



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

WP10 Advanced Accelerator Technologies

Prof. Toms TORIMS, Riga Technical University

I.FAST Open Steering Committee Meeting #10

14 December 2023



WP10 Milestones

MS43	Dissemination and communication plan	10.1	12	Report	Done
MS44	Survey on current AM applications in accelerators and expected new developments	10.2	30	Report	Done
MS45	Survey on current AM repair technologies for accelerator and list of possible applications	10.3	24	Report	Done
MS46	Performance of Superconductive Cavities made by AM technology by Nb or Cu with Nb thin spattered film on the internal surface	10.4	12	Report	Ongoing – extension requested
MS47	First NEG coated samples are installed on SR beamline at DLS and Soleil	10.5	12	Report	Done
MS48	ML model selection and implementation plan	10.6	18	Report	Done
MS49	Delivery of an electro-optic waveguide prototype for demonstration at RHUL test bench	10.7	12	Laboratory prototype in operation	Done

WP10 Deliverables

Deliverables related to WP10	
<p>D10.1: Potential AM applications in accelerators. <i>Report on output of the survey on AM applications, further needs for the accelerator community, and perspective developments.</i></p>	<p>30 Done</p>
<p>D10.2: Survey of AM applications and strategies for repairing accelerator components by AM. <i>Report listing possible strategies and technologies for repairing of parts.</i></p>	<p>24 Done</p>
<p>D10.3: Additive-manufactured Superconductive RF cavities. <i>Production and tests of superconductive RF cavities, made by Nb and/or Cu coated by an Nb thin film.</i></p>	<p>12 18 Done</p>
<p>D10.4: First PSD data from NEG coating. <i>First PSD data from NEG coating reported.</i></p>	<p>36 Ongoing</p>
<p>D10.5: Technical Report on machine learning at ESS. <i>Evaluation and verification results, architecture of the final implementation, and achieved performance at the ESS facility.</i></p>	<p>34 46 Ongoing - extension requested</p>
<p>D10.6: Electro-optic performance report. <i>Final report on the performance of the electro-optic pick-up prototype with beam.</i></p>	<p>24 Done</p>

Task 10.1

Coordination and communication

- *Overall WP coordination, monitoring of progress and technical actions*
- *To **identify and promote novel technologies** to improve performance of particle accelerators*
- *Promote **communication strategies** on opportunities offered by new technologies for accelerators*

T10.1 update on activities - *some highlights only*

- 57 meetings and events <https://indico.cern.ch/category/13515/>
- Last one (19th meeting) in-person in INFN / LNL Padua on 23-24 Oct
- 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:

- Participation in the major **conferences – see updates below**
- 15+ **scientific papers**, and counting
- Presence and **visibility** in the major AM exhibition “Formnext”
- **New European industrial partners** engaged



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Task 10.2 - update

AM – Survey of applications and potential developments

On behalf of:

Prof. Maurizio VEDANI / PoliMi



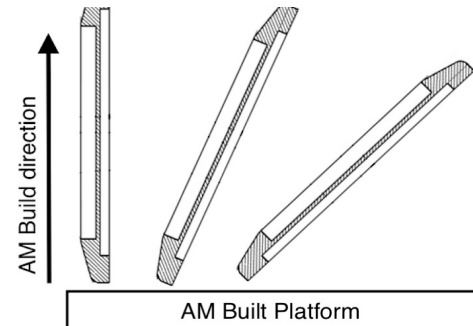
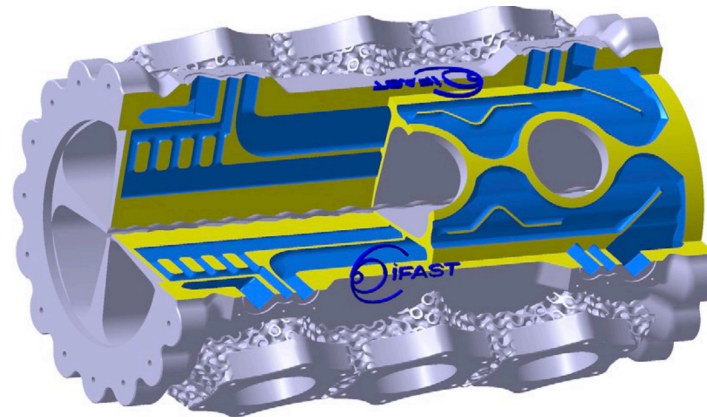
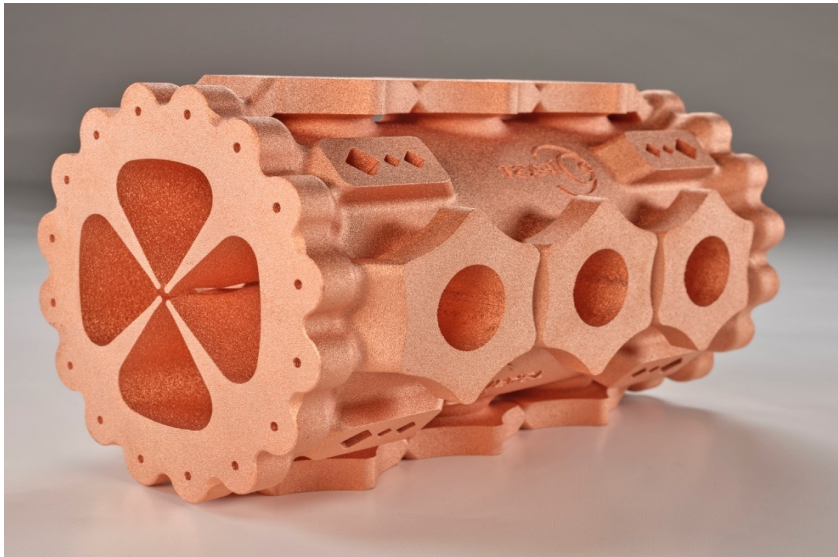
Task 10.2 objectives

Additive Manufacturing – Survey of applications and potential developments M1 – M36

- Survey of current **AM applications in accelerators** and identification of needs for future development and research actions.
- **Promote initiatives** to identify how AM can address the needs of the accelerator community.
- **Define strategic directions** for future AM technologies and foster their impact on accelerator applications (sterilisation, medicine, industry),
- **Identify technology barrier** and challenges.

Main results and running activities

- Design, manufacturing and testing (dimensional tolerances, roughness, vacuum, RF, ...) of a full section RFQ
- Post printing finishing processes
- Vacuum tightness by tests on membranes
- High-voltage behaviour of Cu electrodes



Reporting & dissemination

- All data are available in Deliverable D10.1:
- A report on output of the survey on AM applications, further needs for the accelerator community, and perspective developments
- Partners are quite active on publication of journal papers and contributing to conferences & seminars



I.FAST

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

DELIVERABLE REPORT

Potential AM applications in accelerators

DELIVERABLE: D10.1

Document identifier:	IFAST-D10.1
Due date of deliverable:	End of Month 30 (Oct 2023)
Report release date:	04/10/2023
Work package:	WP10: Advanced Accelerator Technologies
Lead beneficiary:	PoliMi
Document status:	Draft



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Task 10.3 - update

Refurbishment of accelerator components by Additive Manufacturing technologies

On behalf of:

Dr. Andris RATKUS / RTU



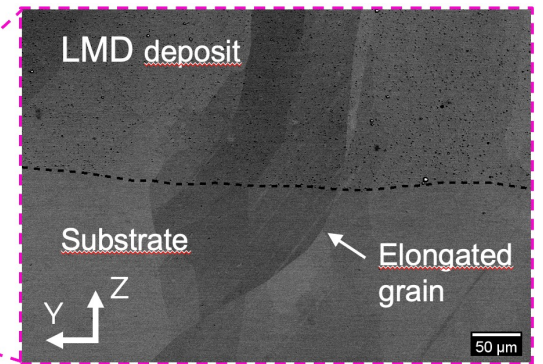
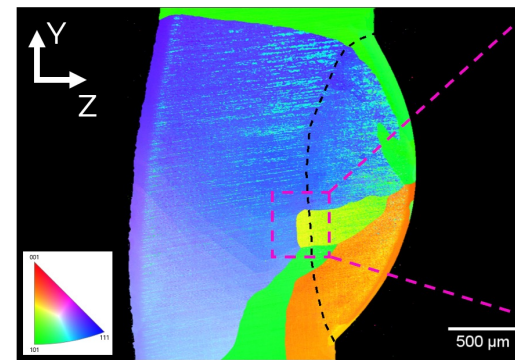
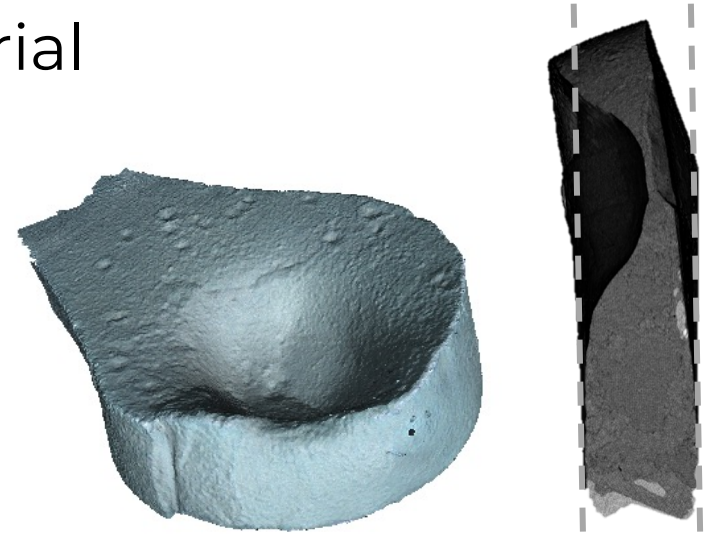
Task 10.3

Refurbishment of accelerator components by Additive Manufacturing technologies

- Definition of **applications and components for the repair** activities in the accelerator components by AM
- Identification of **AM strategies** that can be adopted to repair parts
- Study **post-processing methods** to control surface roughness and surface cleanliness of AM parts
- Identification of a sample **demonstration prototype** of AM repaired unit for an accelerator

T10.3 achievements - recap

- **Demonstrated AM abilities** with exotic material
- Successfully used two DED AM technologies
- Parameters diapasons were determined
- Tested several **repair strategies**



Hardness: $315.3 \pm 10.3 \text{ HV}_{0.05}$



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Task 10.4 - update

Development of AM-manufactured superconductive RF cavities

On behalf of:

Dr. Adriano PEPATO / INFN



Task 10.4: Development of AM-manufactured superconductive RF cavities

- Develop the **design approach and test** relevant properties of **AM-manufactured Niobium RF cavities**
- Develop the **design approach and test** relevant properties of **AM-manufactured Ultra-Pure Cu-made RF** body cavities - coated by a Niobium thin layer at the inner surface
- Both to be tested at room and at cryogenic temperature

T10.4 achievements

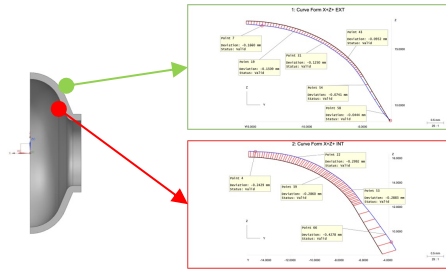
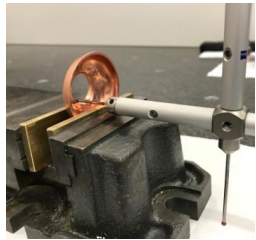
- Cavities produced by AM

Cu cavities

First prototypes:

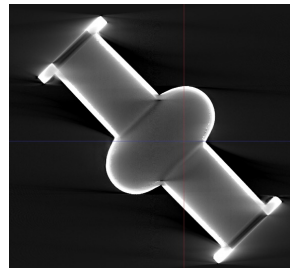


- Geometry verifications



6 GHz seamless cavities:

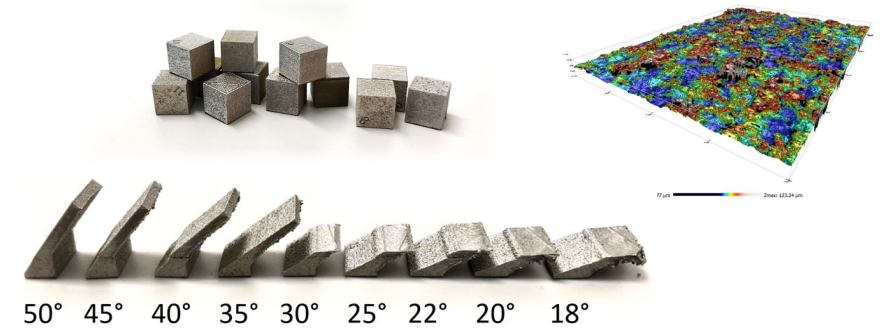
- Red laser
- Green laser



Nb cavities

Material characterization and process parameters optimization:

- Density
- Critical angle
- Down-skin
- Contour



6 GHz seamless cavities production



Task 10.5

Already reported by Dr. Oleg
Malyshev

Thank you Oleg!



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Task 10.6 Highlights

On behalf of:

Thomas Shea, Irena Dolenc Kittelmann (ESS)

Karlis Berkolds (RTU)



Task 10.6

Machine Learning Techniques for Accelerator and Target Diagnostics

- *Long term mission: **Develop low-latency Machine Learning (ML) techniques to improve performance and availability of high-power facilities at the intensity frontier.***
- *Goal: Identify signatures of potential **errant beam conditions***
- *Scope:*

*Assess the **predictive capabilities** of selected ML models*

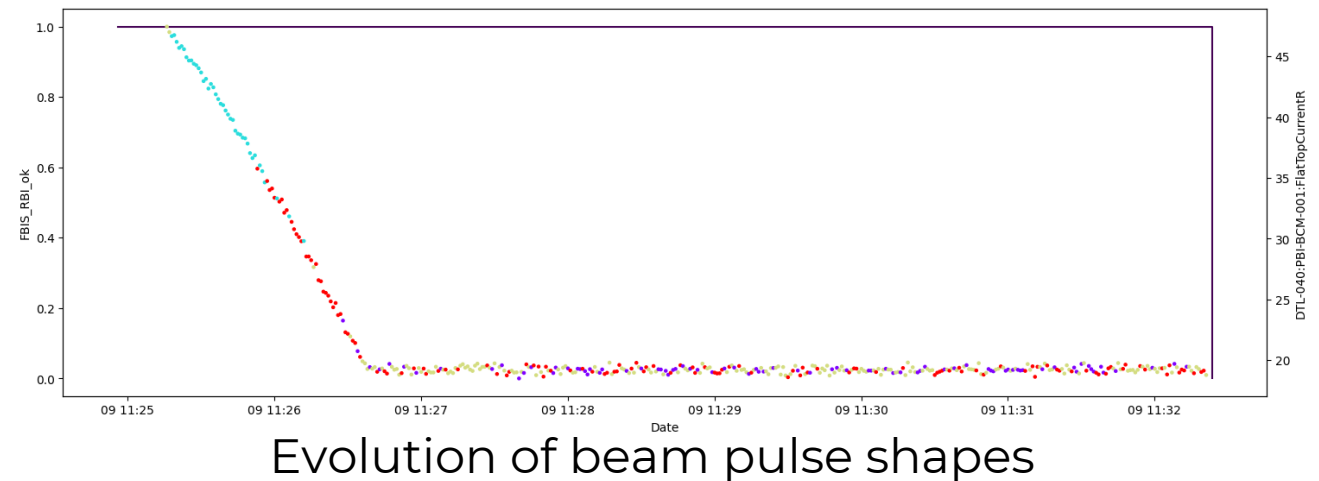
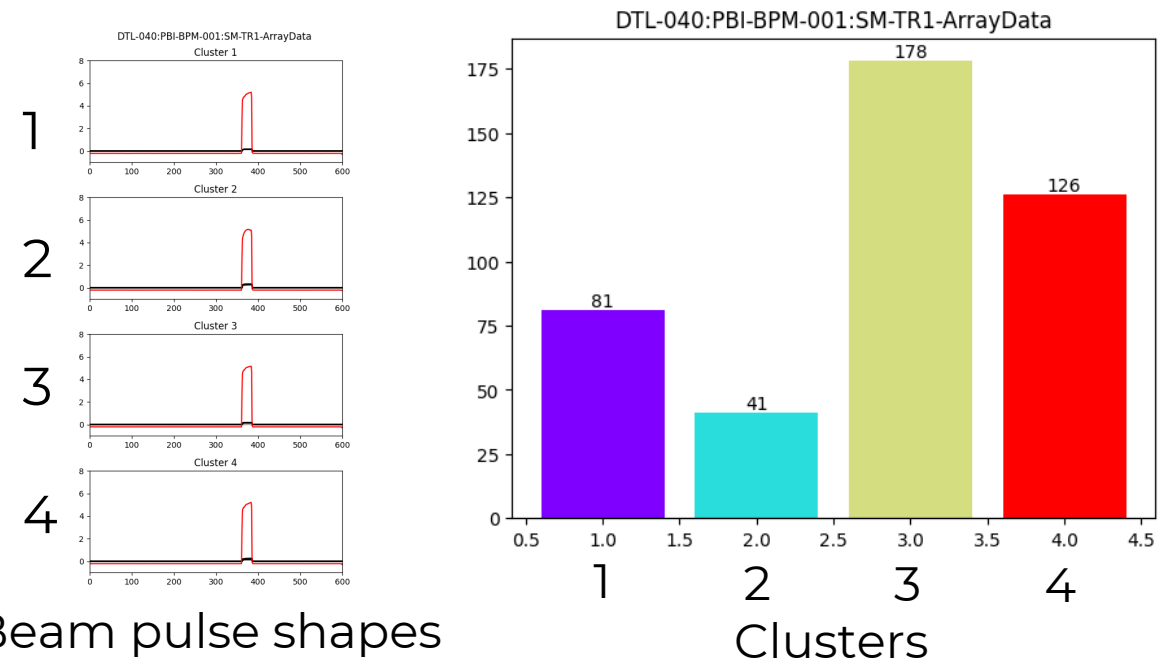
*Prototype: **proof of principle demonstration***

The most promising ML model to be implemented on a low-latency network of FPGAs processing signals from array of detector channels

Recent Highlight – Cluster Analysis of ESS Linac Beam Pulse Measurements



- We are clustering DTL 1 to 4 Beam Position Monitor Waveforms according to their shapes using a k-shape algorithm. In the result, each Waveform is labelled as belonging to one of the clusters, and the typical waveform shape of each cluster is determined.
- After that, we combine beam interlock status and DTL BCM Current data with clustering results to show how each waveform evolves during the run
- Significant effort to extract and curate data from dataset approaching petabyte scale
- Progress toward pulse classification and intelligent data acquisition
- MOU signed to allow access to ORNL/SNS data



Extension to Task 10.6

- We propose a zero-cost, 12-month extension to Task 10.6
- The participants in this task will remain engaged in the I.FAST project through month 48
- The final report (Del10.5 “Technical Report on Machine Learning at ESS”) **will be delivered in month 46**
- The change is driven by the 2022 rebaseline of the ESS project that shifted the schedule of the commissioning campaigns that deliver critical data sets
- This extension will allow us to incorporate additional curated commissioning data into assessment of ML models, thus increasing the quality of the final report

Task 10.7

Development of electro-optical waveguide sensors as beam electric field sensors

• *Develop novel electric field sensors based on electro-optical waveguide sensors*

**Completed with the flying colours!
Bravo!**

Demonstrate the capability to optically measure the intra-bunch transverse displacement of a passing relativistic bunch, with a bandwidth that is beyond state-of-the-art

Publications in pipeline

- Abstract submitted
- 15th International Particle Accelerator Conference
- **“Perspectives and recent achievements on additive manufacturing technologies for accelerators”**
- Based on I.FAST Deliverables 10.1; 10.2; 10.3 and 10.4



Publications in pipeline

- Paper submitted
- ASME Conference “2024 International Manufacturing Science & Engineering Conference (MSEC)” – June 2024
- **“Advances of the metal additive manufacturing in the field of particle accelerators”**
- Based on I.FAST Deliverables 10.1 and 10.2



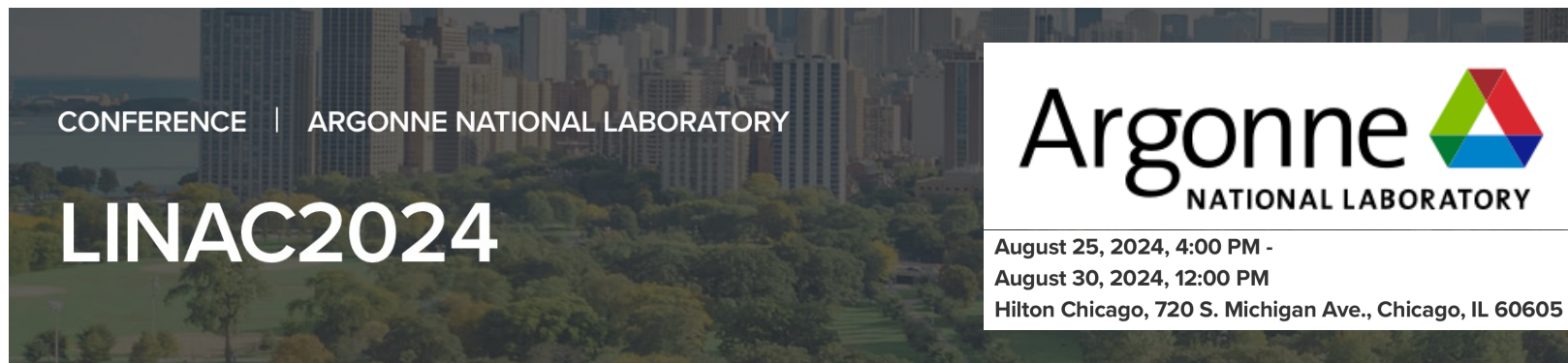
MSEC 2024

University of Tennessee - Knoxville, Knoxville, Tennessee, USA
Hosted by University of Tennessee - Knoxville
June 17 - 21, 2024



Publications in pipeline

- Contribution proposed
- 32nd Linear Accelerator Conference (LINAC)
- Based on I.FAST Deliverables 10.1; 10.2 and 10.3



Widening our collaboration

3rd iteration

Full-size
optimised
RFQ

made by



TruPrint 5000
Green Edition

390 mm

.NEW

TRUMPF
TruPrint 5000

Multilaser



Widening our collaboration

AM Seminars, talks and discussions with experts

- 20 Jan 2023 – University of Frankfurt
- 16 March 2023 – PSI, Villigen
- 6 April 2023 – LPSC, Grenoble
- 15 Nov 2023 – STFC, Daresbury

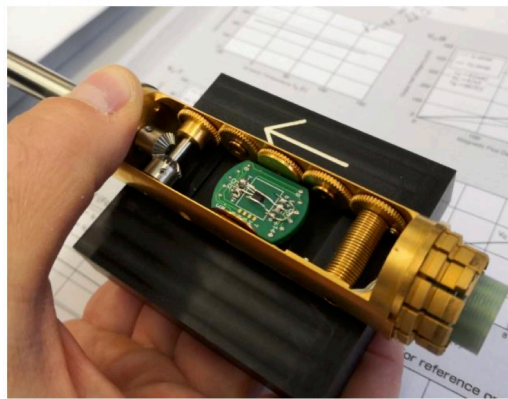
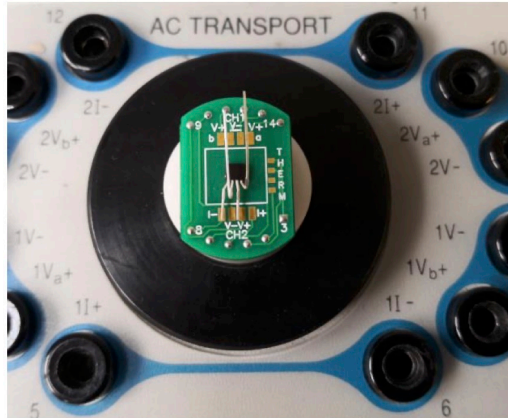


Widening our collaboration

- Plasma post-processing of AM sample part
- Engaging with Dr. Hendrik Hähnel



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

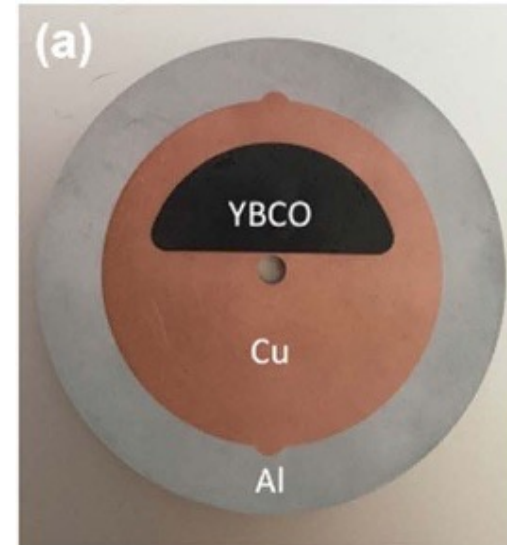
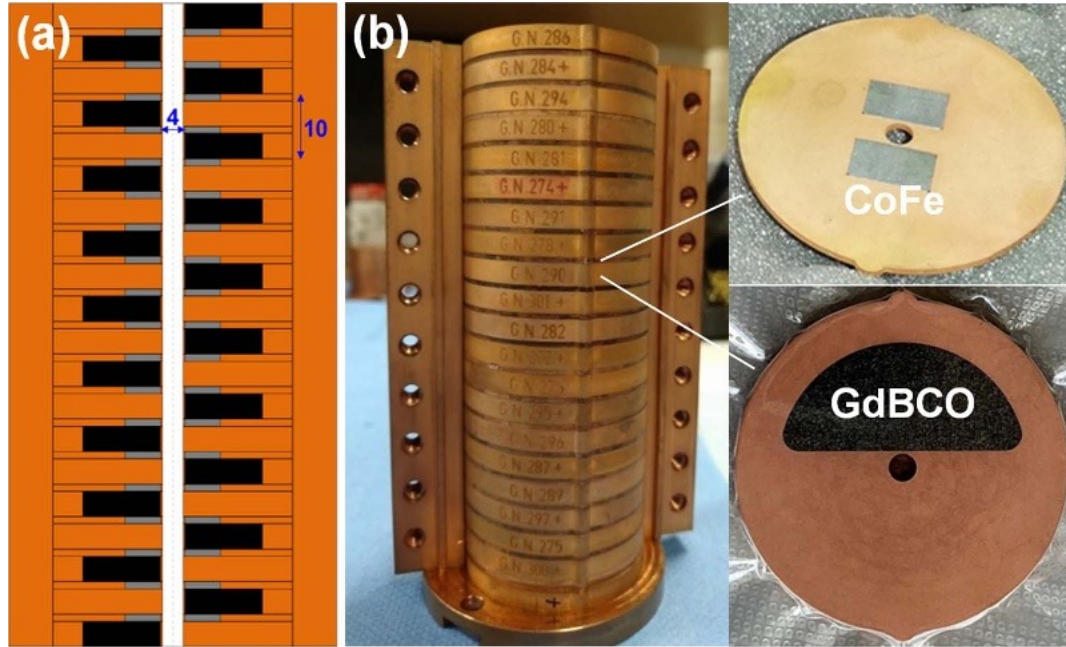
PAUL SCHERRER INSTITUT
PSI

In collaboration with:

Insertion Device Group, Photon Science Division of PSI



Pure copper printing on YBCO disk?



High-temperature superconducting undulator

Half-moon shaped YBCO disk

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

<https://doi.org/10.1088/1361-6668/accl1a8>

In collaboration with:

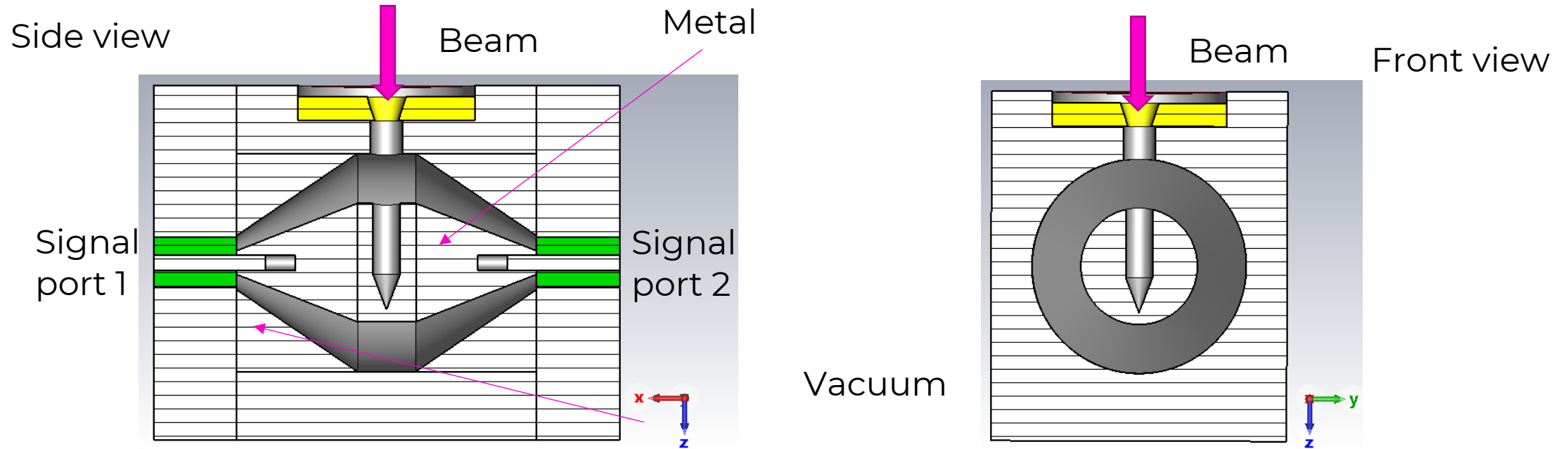
Insertion Device Group, Photon Science Division of PSI



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Work is going-on!

Fast Faraday Cup for AM

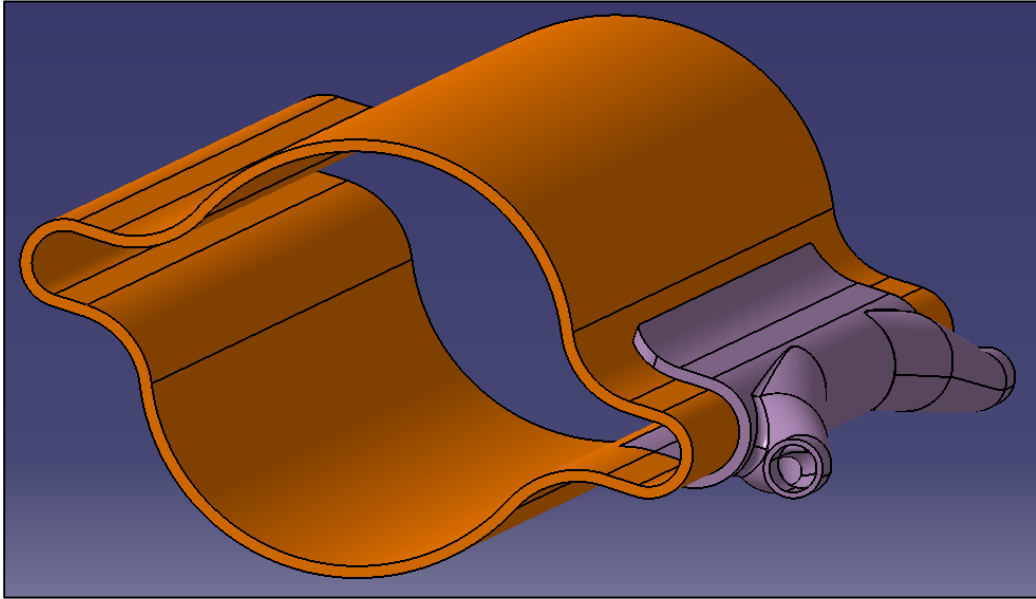
Unpublished design
S. Klapproth, R. Singh



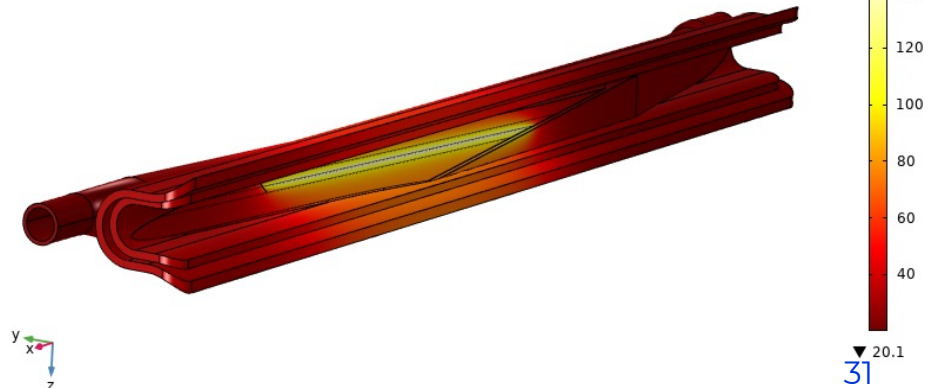
This work is supported by the German Federal Ministry of Education and Research (BMBF) under contract no. 05P21RORB2. Joint Project 05P2021 - R&D Accelerator (DIAGNOSE).

- 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

FCC – ee: Additive Manufacturing Synchrotron Radiation Absorber



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



I.FAST Open Steering Committee Meeting #10
14 December 2023

Work is going-on!

Additive Manufacturing

There is HUGE interest within our community and beyond

Thank you for this opportunity!



Thank you for your attention!



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Back-up slides

WP10 perfectly relevant and are having impact

- Define strategic directions for the **use of AM** technologies on accelerator applications
- Identification of **AM strategies** that can be adopted to **repair parts**
- Develop the **design approach and test** relevant properties of AM-manufactured RF cavities
- **Build facilities** for photon stimulated desorption (PSD) yield measurement on beamlines
- Develop Machine Learning (ML) **predictive algorithms** to diagnose and protect high power accelerators
- Develop **novel electric-field sensors** to address new challenges in fast time response beam instrumentation

Workshops and meetings

How can AM address the needs of the accelerator community?

- Type 1: I.FAST meetings - project partners and community
- Type 2: “in situ” meetings with industry and other research institutions – relevant non-project partners and interested parties
- Type 3: “Horizontal Workshops” open to everyone (linked to project Annual Meetings) - transverse multidisciplinary Workshops and events involving two or more I.FAST WPs.
- Type 4: oral contribution to the international conferences and seminars

Workshops and meetings - in practice

- Type 1: I.FAST meetings
 - WP10 meeting, Task 10.1-10.7 meetings
 - Steering Committee, progress meetings, Annual meetings
 - I.FAST industrial workshop – Task 3.1
 - European Advanced Accelerator Concepts workshop – Task 6.1
- Type 2: meetings “in situ” with industry and other research institutions
 - Roesler, AM Solutions - current
 - meeting in Paris @ CNRS (Feb 2022) with designated workshop on AM applied to accelerators + series of other seminars in various locations
- Type 3: “Horizontal workshops” open to all (linked to project meetings)
 - I.FAST Annual Meeting @CERN (May 2022) - AM
- Type 4: conferences
 - special interest in IPAC23 @Venice (May 2023)