3^{rd} I.FAST Annual Meeting

Luca Garolfi (CERN & TERA Foundation)
WP4, Task Leader 4.1 & 4.2

The I.FAST Innovation Fund

Task 4.2, **Management of the Innovation Fund**.

1 M€ funding to an internal competitive call for innovative projects, starting early 2023, for a duration of 2 years

1. Funding between 100 and 200 k€ per project
2. Consortium: at least one I.FAST beneficiary and one industry;
3. Initial TRL 3 or higher (from proof-of-concept to laboratory/environment validation);
4. Project contributes to improving sustainability of particle accelerator technologies;
5. Project must have potential for industrialisation or commercialisation
6. Project must have potential to attract more resources than what deployed by IFAST alone.

18 projects submitted, 8 selected by a 10-member Evaluation Committee:

2 on high-efficiency RF sources, 2 on superconductivity, 2 on particle sources, 1 on laser plasma acceleration, 1 on additive manufacturing.

Smooth selection procedure and excellent quality of the selected projects!

Deliverables & Milestones

Year 2

No.	Deliverable	WP	Task	Planned Delivery	Delivery	Status	Reports
D4.1	Evaluation criteria for IIF projects, and Evaluation Body	4	4.1	M20	01/02/2023	Achieved	Report
D4.2	IIF Projects awarding	4	4.2	M24	03/04/2023	Achieved	Report

all the deliverables achieved on time in 2023

Year 3

No.	Milestone	Task	Planned Delivery	Delivery	Report
MS11	IIF Projects interim progress	4.2	M36		

end of April 2024:
It will be completed on time, most of the reports already received

Year 4

No.	Milestone	Task	Planned Delivery	Delivery	Report
MS12	IIF Projects final progress	4.2	M46		

expected in 2025

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The selected projects

High-efficiency RF sources

- ***Development** of **Highly Efficient** Megawatt Class **Cross Field Vacuum Tube Amplifier for Particle Accelerators** Driven by a Solid-State Power Amplifier at 750 MHz.*
- ***Permanent Magnet for High Efficiency Klystrons** (PM4HEK).*

Additive manufacturing

- ***Demonstration of Additive Manufacturing for** Large and Complex Shaped **Vacuum Chambers** by **Plasma Metal Deposition (PMD®)***

Superconducting materials

- ***Millisecond flash lamp treatment for SRF** accelerating **cavities**.*
- ***High-Temperature High-Gradient Superconductors** (HIGHEST).*

Laser-plasma acceleration

- *KAIO **Accelerator*** ← (dedicated presentation)

Particle sources

- ***AM applications** of refractory metals **for ION Source** cavities* ← (dedicated presentation)
- *A **Field Emission Cathode** for a **TW RF gun** for High Brightness Beams in Industrial and Small Research Facility Settings (FE Cathode)*

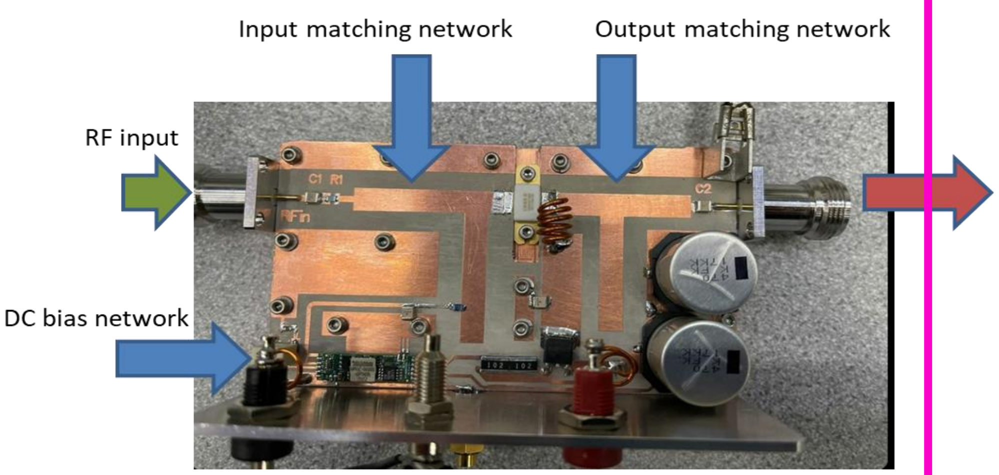
Development of Highly Efficient Megawatt Class ***Cross Field Vacuum Tube Amplifier for Particle Accelerators*** *Driven by a Solid-State Power Amplifier at 750 MHz*

Anshu Sharan Singh and Dragos Dancila
(Uppsala University - FREIA)
Industrial partners: Scandinova AB and Exir Broadcasting AB

Technical Summary

The aim of this application is to synergize the power generation technologies and develop the megawatt class CFA as the **main amplifier of the SSPA driver**, to achieve the **highest degree** of **efficiency**, **cost-effectiveness**, **compactness** and **lifetime** of an. **RF power source for particle accelerator and medical applications**

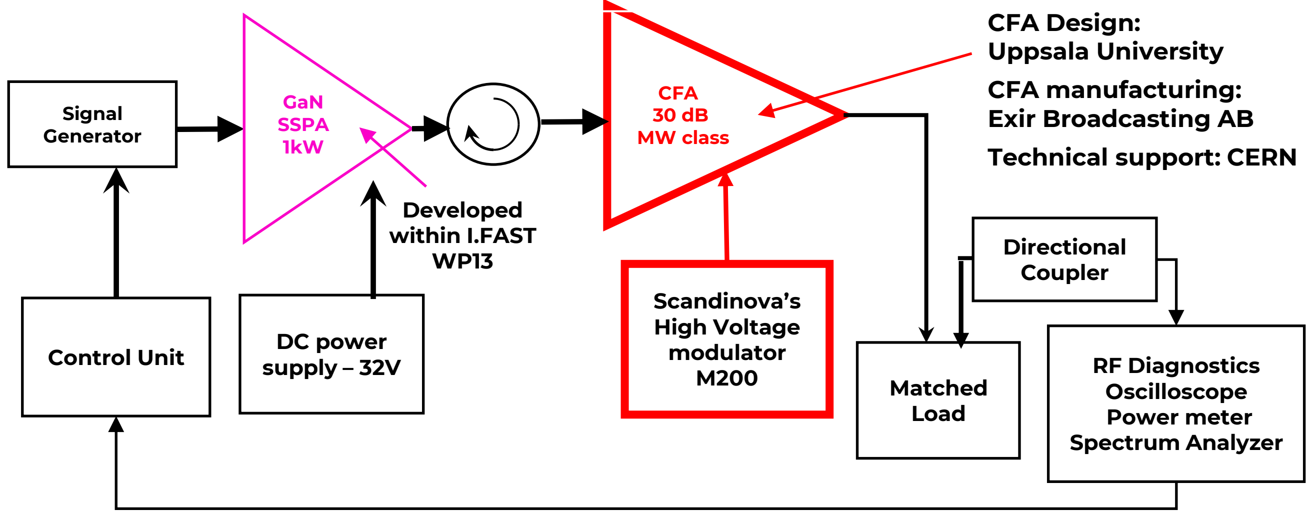
750 MHz GaN amplifier developed in I.FAST WP13



Measured output power of 205 W possible, with a signal gain of 17 dB and an efficiency of 84% in compression.
This will be further combined till kilowatt level.

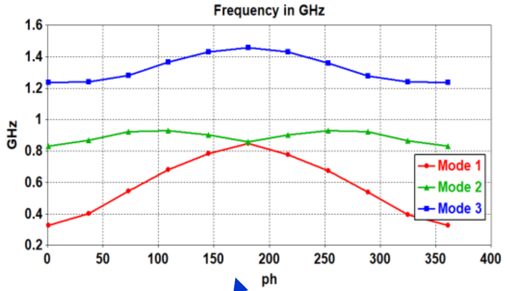
Pout = 53 dBm (60 dBm with combiner) / PAE = 84% @ 750 MHz

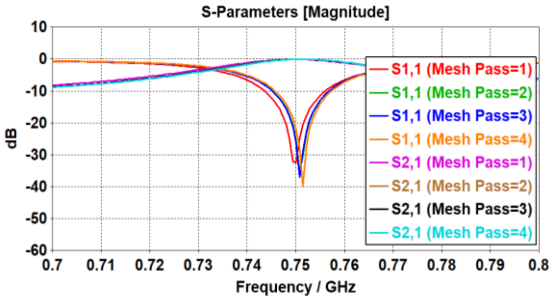
Block Diagram of new SSPA driven CFA – this project

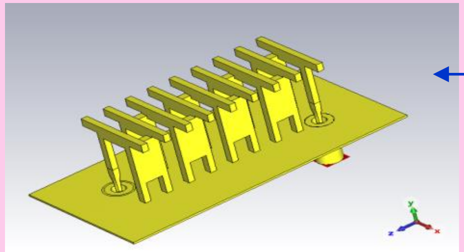


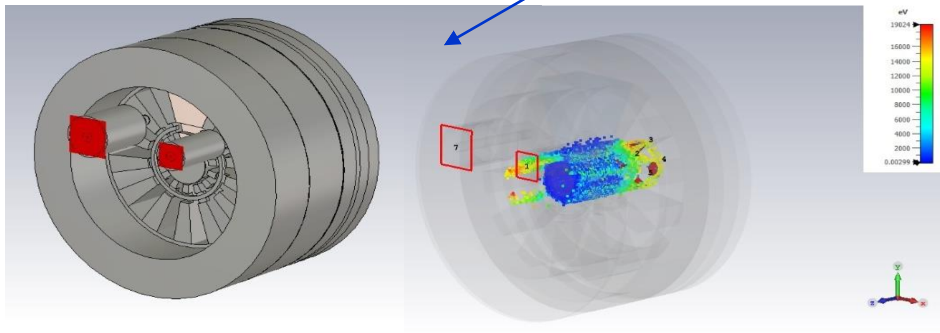
- **The current status of the CFA technology is that most of the research was done before solid state power amplifier (SSPA) were available as driver.**

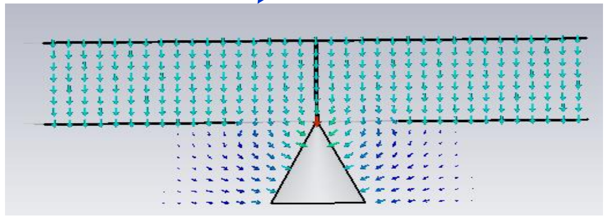
Solution identified

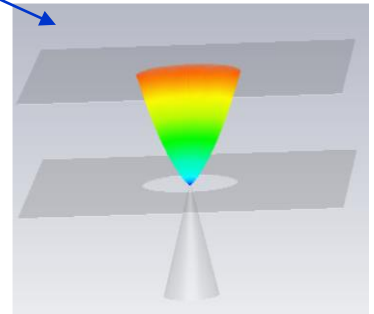




Parameter	Component level Innovation	Study
Frequency **VSWR**	Slow wave structure Coupler 	Modelling Eigenmode Simulation Scattering parameter study
Efficiency	Re-entrant Distributed Emission Misaligned A-K gap & nonuniform SWS period Employment of a permanent magnet-based system	PIC efforts on reentrant CFA Solution identified Magnetostatic simulation
Longevity	Cold emission secondary cathodes	Simulation ongoing field emitters







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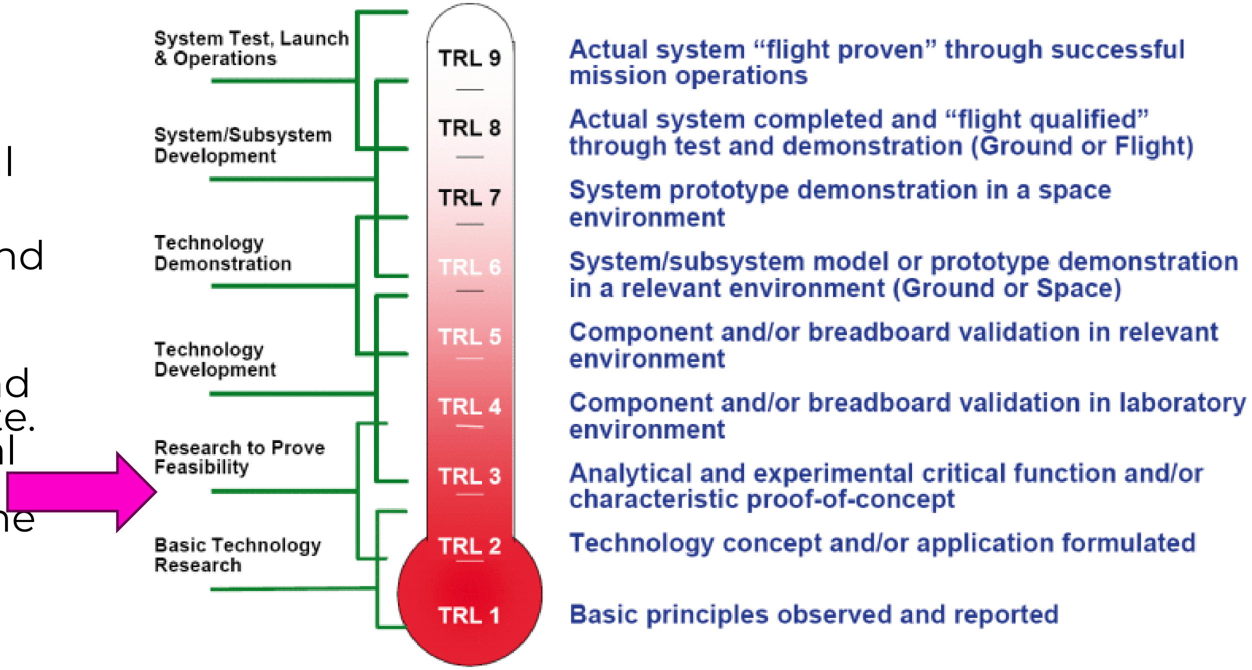
Industrialisation & Environmental impact

- They have developed a **computational model**
- They are investigating the components independently and performing the **PIC simulation** to determine the beam wave parameter
- The **Slow Wave Structure was designed and fabricated by the Uppsala University workshop March 2024**

Manufactured devices status 19 March 2024

- The **TRL = 3**, as they need to complete the **modelling and numerical simulations** before starting the experimental phases
- **Scandinova, AB** as the industrial partner will play a crucial role in providing **experimental devices**
- **Exir Broadcasting AB** will contribute with **waveguides** and advanced **manufacturing** capabilities for high power microwave sources
- CFA have immediate **impact on energy consumption** and thus on **the overall efficiency** of the system they integrate. With identical RF output power, an increase of operational efficiency from 50% to 80% will reduce the energy consumption by 48%. Consequently, the DC supply and the cooling system could be become smaller.



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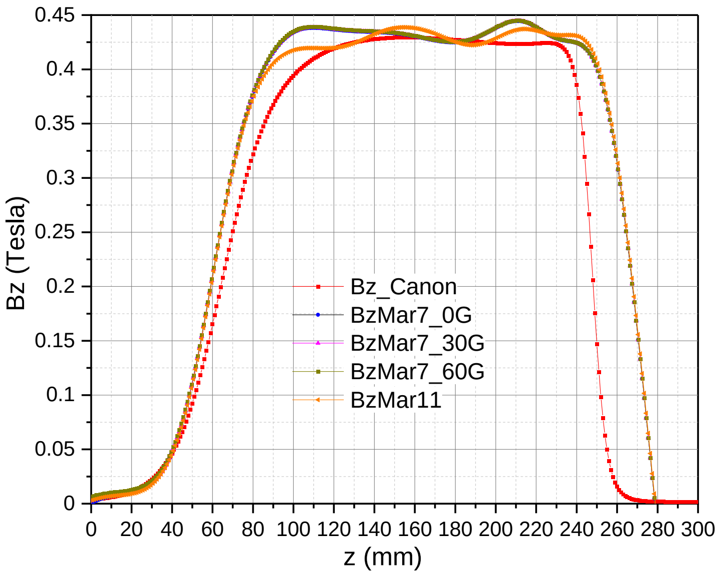
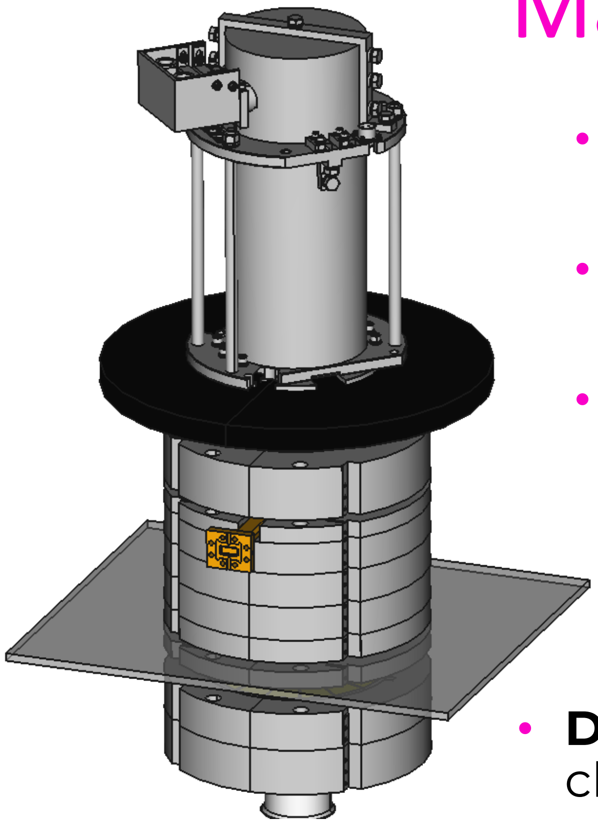
Permanent Magnet for High Efficiency Klystrons *(PM4HEK)*

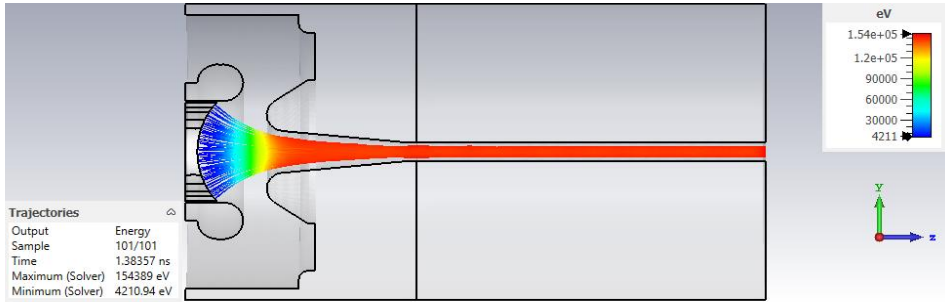
Nuria Catalan Lasheras, CERN,
Elytt Spain

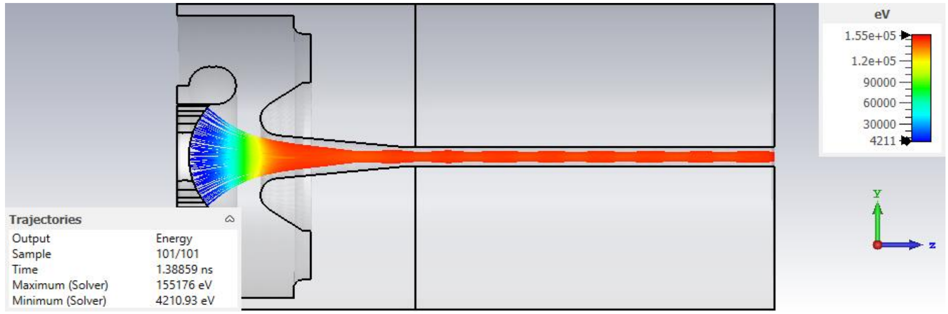


Main achievements

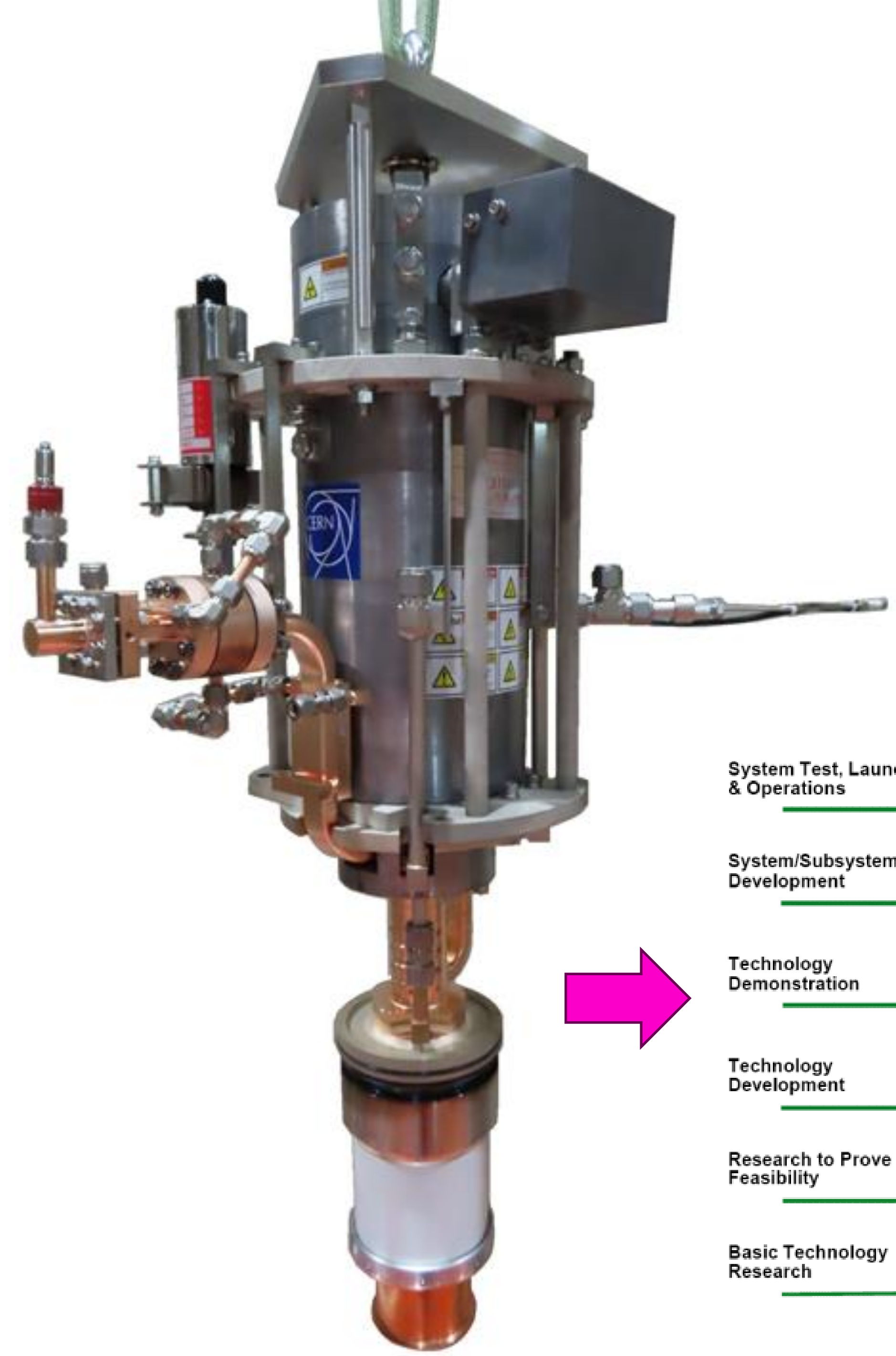


- After many iterations, the **design** of the **magnetic channel** is finished
- Corresponds to the electro-magnet on the tube area
- **Drawings ready** for quotation



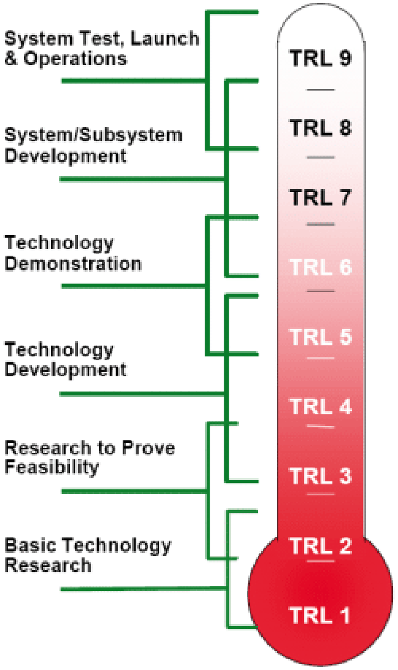


- **Dynamics inside the klystron** checked by CERN simulations
- **Full transmission along the tube**
- Small oscillations still preserving the efficiency



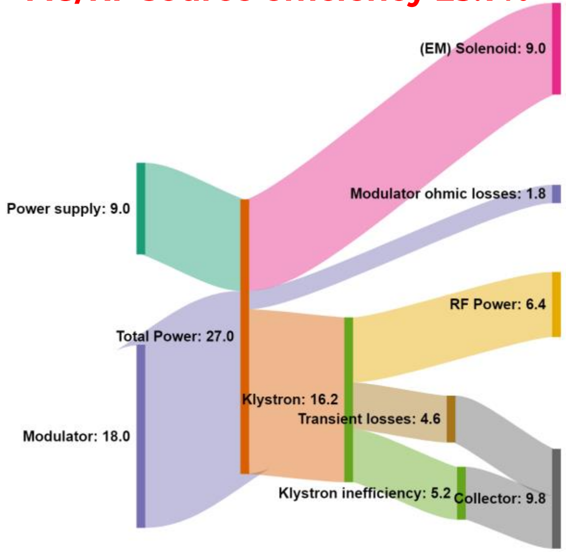
Industrialization

- Three-partite meeting with **CANON ETD** as the **main collaborator and client for the solenoid**
- Some changes would be required on the klystron model
- Very interested on the development
- Waiting for technical details for adapted model

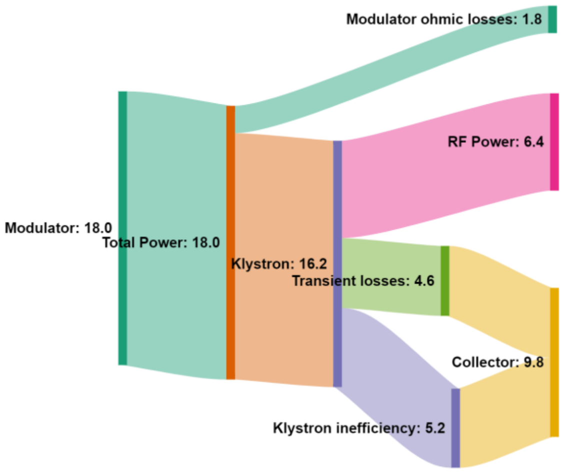


Environmental impact

New HE Klystron
AC/RF source efficiency 23.7%



HE tube with PM solenoid
AC/RF source efficiency 35.5%



Hvac - Demonstration of ***Additive Manufacturing for Large and Complex*** *Shaped* ***Vacuum Chambers by Plasma Metal Deposition (PMD®)***

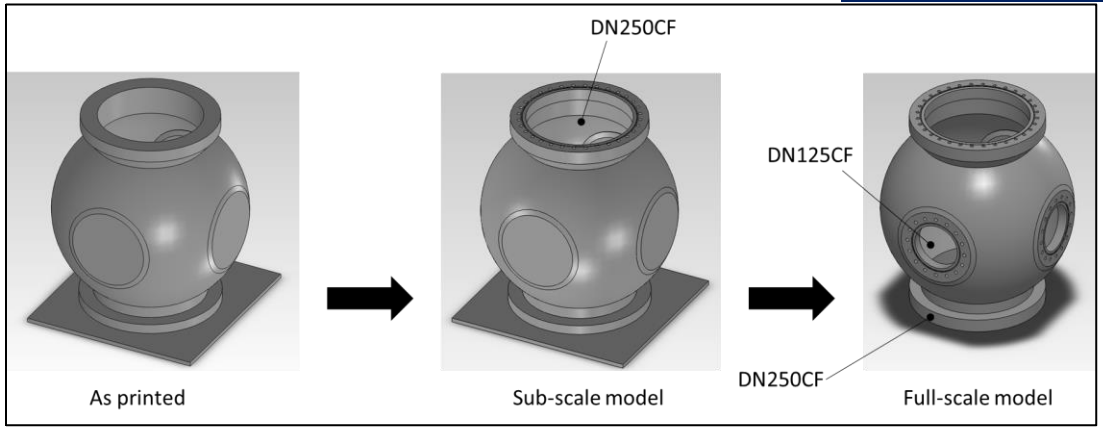
Dr. Carlos Belei, Project Engineer – RHP Technology GmbH

Dr. Erich Neubauer, Managing Director – RHP Technology GmbH

Activities performed from February 2023 to March 2024

- Vacuum chamber design [**RHP/**SBI]
  - Based on literature and commercially available options.
- Tool path generation [**RHP**]
  - Delay of 2 months; tool path required an strategy that had not been adopted before.
- Manufacturing of vacuum chamber [**RHP/**SBI]
  - 3D-Printing had a delay of 2 months; unforseen issues appeared, which required contingency actions;
  - Upper flange machined.
- Evaluation of vacuum chamber [**RHP**]
  - Vacuum tests using mechanical and turbomolecular pumps in series (up to 10^{-6} mbar);
  - 3D-scanning with a laser-based system.
- Technology assessment [**SBI**/RHP]
  - Machine concepts for upscaling proposed by SBI;
  - Prospect of patenting printing strategies investigated with patent attorney.

Designing



Spherical chamber, 6 flanges:
- 2x DN250CF (top, bottom
- 2x DN125CF (side faces)

Internal diameter of 450 mm, volume of 52 l.

3D-printing

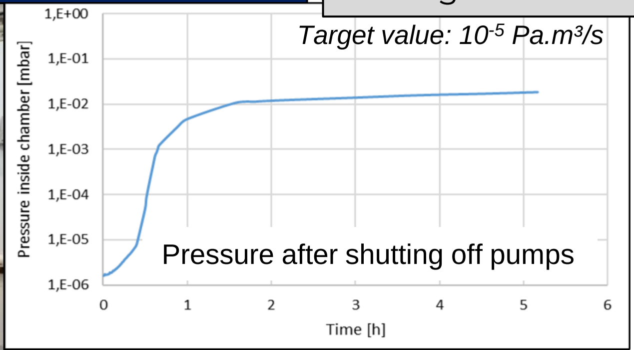
Machining

Chamber evaluation

Vacuum testing

1) *Mechanical pump (roughening)*
2) *Turbomolecular pump*

Leakage rate = 2.9 x 10^{-6} Pa.m³/s



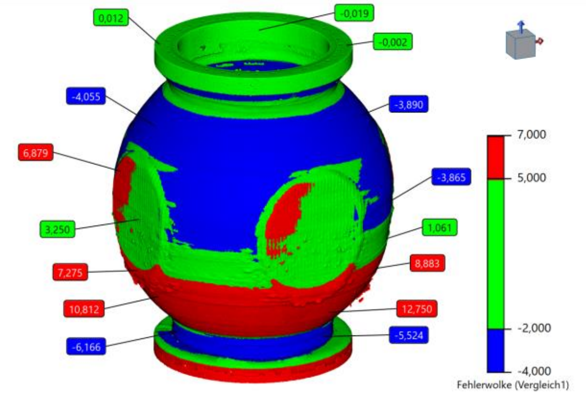
No distortions detected post vacuum test

Limit of the pumping system reached (1.6 x 10^{-6} mbar)

Chamber pumped for 108 hours

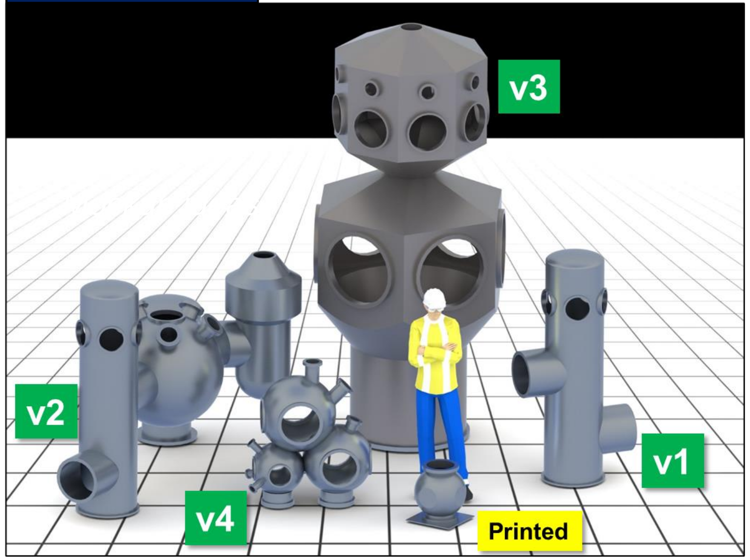
3D-scanning

Deviation from CAD model [mm]



Technology assessment

Upscaling

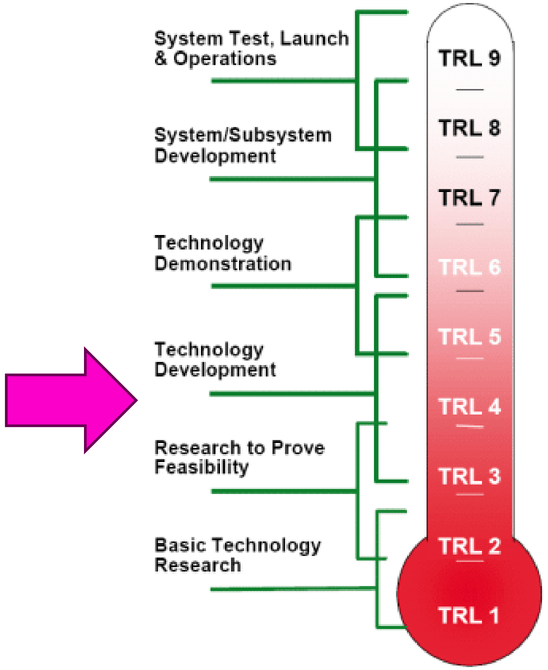


Different mockup chambers designed, with features not possible to be printed with the current machinery.

Chamber „v3“ selected for designing a machine concept capable of reproducing it.

Industrialization

- The manufacturing **technology** was validated in the **lab environment (TRL4)**
- The **goal** is the **validation** of the technology on a **complex and larger chamber** including the **exposure of the chamber to industrial relevant environment => TRL 5**
- In a **next step** the same system can be tested and **demonstrated including various analytical devices**. This includes demonstration of **multiple bake out and cycling (TRL6)**



Environmental impact

- **The Plasma Metal Deposition** allows to realize complex shapes and **reduces the amount of raw materials required**.
- Therefore, **Plasma Metal Deposition has a positive impact** on the **environmental footprint**

High-Temperature High-Gradient Superconductors *("HIGHEST")*

Sergio Calatroni, CERN
CSIC-ICMAB (public research center, ES)
KIT Campus Transfer GmbH (KCT) (private company, DE)
SLAC as supporting partner

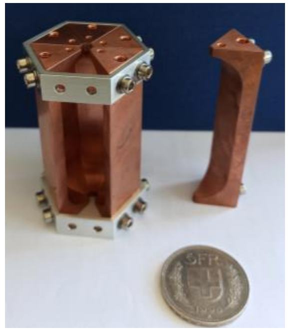
Proposed work plan from 4/2023 to 4/2025

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
WP 1 (CERN)								
Coordination activities								
Samples and substrates procurement		M1						
RF low power characterization of segmented cavities (small tapes)					D1			
Final report								D2
WP 2 (KCT)								
Design and fabrication of sample holder system				M1				
HTS coating of large samples								D1
WP3 (CSIC-ICMAB)								
Coating on discs and segmented cavities for benchmarking (small tapes)				D1				
Measurement of superconducting properties of large size tapes								D2
SLAC supporting partner								
RF high power characterization of 3D coated HTS discs in their mushroom cavity								

Summary of milestones and deliverables

WP1 CERN

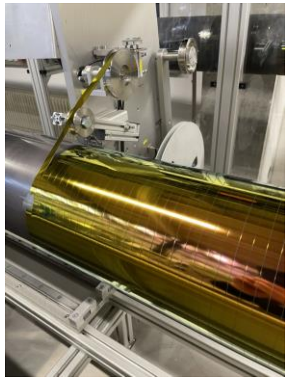
- M1 - **Samples and substrates procurement** (due 12/2023). Achieved but we have some alignment difficulties of the segments still to be solved
- D1 - **RF low power characterization of segmented cavities** (**small tapes**) (due 6/2024). On track with some potential small delays pending the solution of the above difficulties. However, this is mitigated by: CERN



Segmented cavity

WP2 KCT

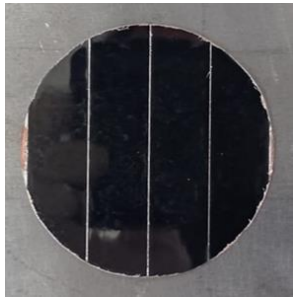
- M1 - **Design and fabrication of sample holder system** (due 3/2024). Achieved well in advance
- D1 - **HTS coating of large samples** (due 3/2025). On track and well under way



Roll to roll coater for HTS tapes

WP3 CSIC

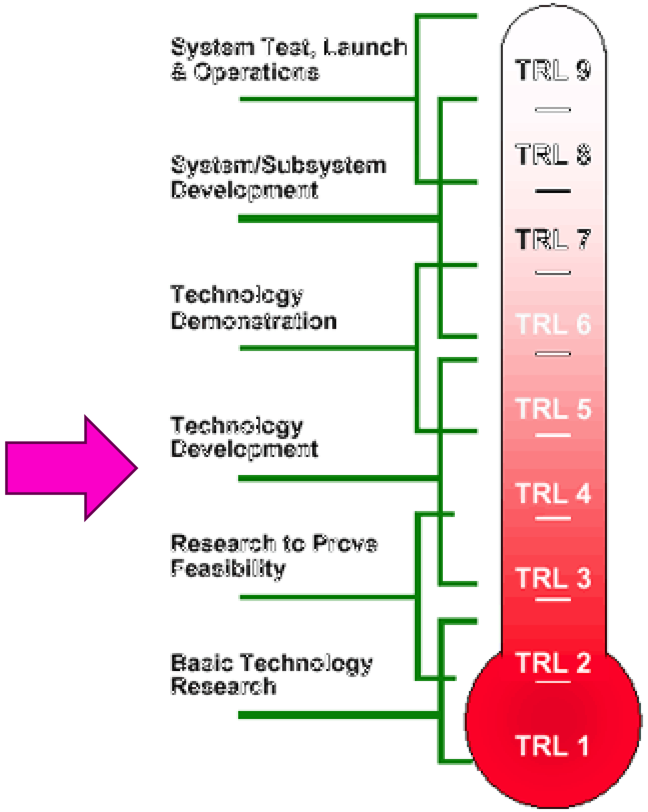
- D1 - **Coating on discs and segmented cavities for benchmarking (small tapes)** (due 3/2024). Achieved for discs, already high-power tested at SLAC (presented at EUCAS 2023 / IPAC 2024) waiting for readiness of segmented cavity
- D2 - **Measurement of superconducting properties of large size tapes** (due 3/2025). On track and well under way, first 40 mm wide tape already characterized



Copper disc coated with 12 mm tapes

Industrial application prospect

- At the end of this study, we aim at consolidating TRL4.
- Prototype pulse compressor with SLAC will demonstrate TRL6.
  - Initially foreseen to be started after completion of HIGHEST
  - Already initiated, on track to be achieved within HIGEST time-frame, or shortly afterwards
  - Activity independent from HIGHEST, but based on our developments and results
- High Interest for this technology from SLAC, Muon Collider Study, Axion detectors (RADES, CAPP)



Environmental impact

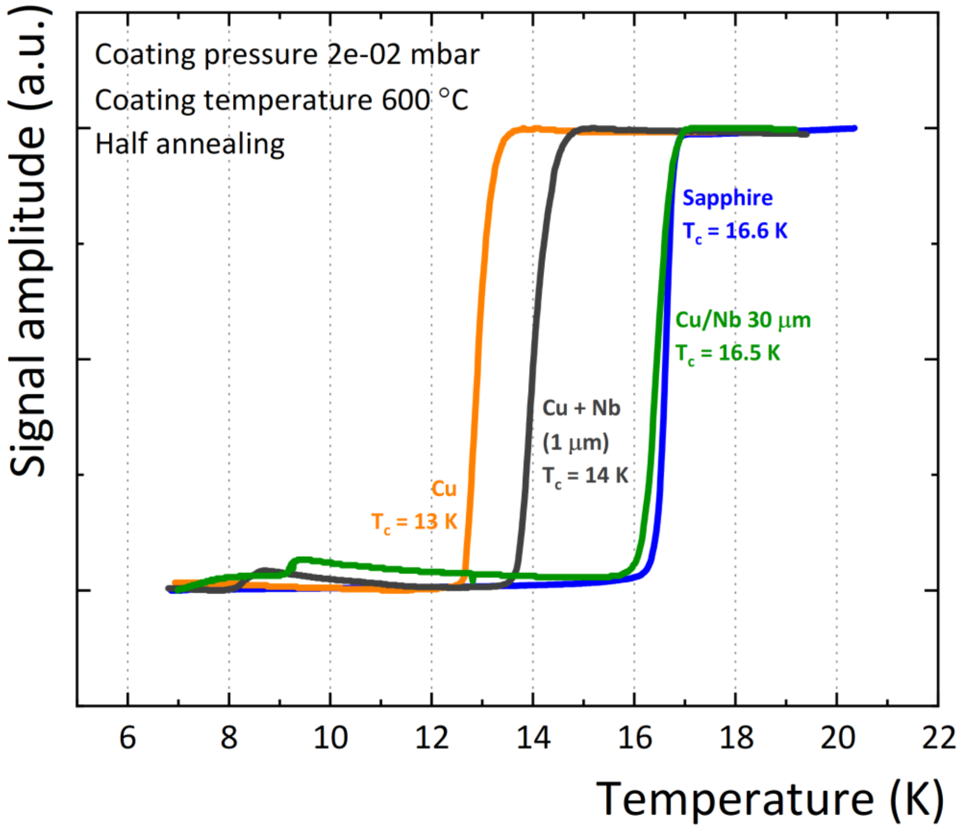
- New-generation collider linacs are expected to use hundreds of MW of electricity
- Energy savings from HTS are in line with current policies of societal impact minimization

Millisecond flash lamp treatment for SRF accelerating cavities

Cristian Pira, INFN
Slawomir Prucnal, HZDR

Goal

- **I.FAST WP9** demonstrate that Tc and performances of Nb_3Sn coating are strongly affected by substrate
- **The goal** of Msec Flash annealing project is to develop a **novel thermal process** to **improve performances of SC coating** by suppressing (reducing) Cu substrate heating

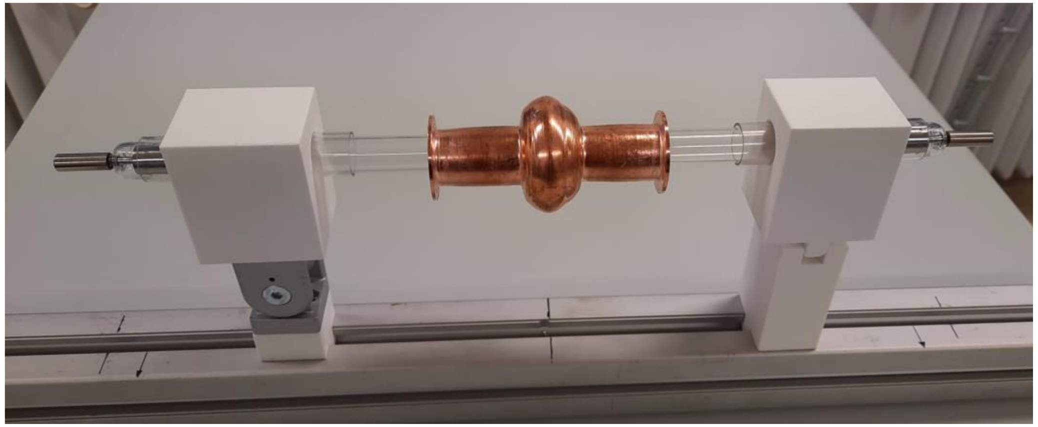


Tc of Nb3Sn coatings depends on the thickness of Nb barrier layer

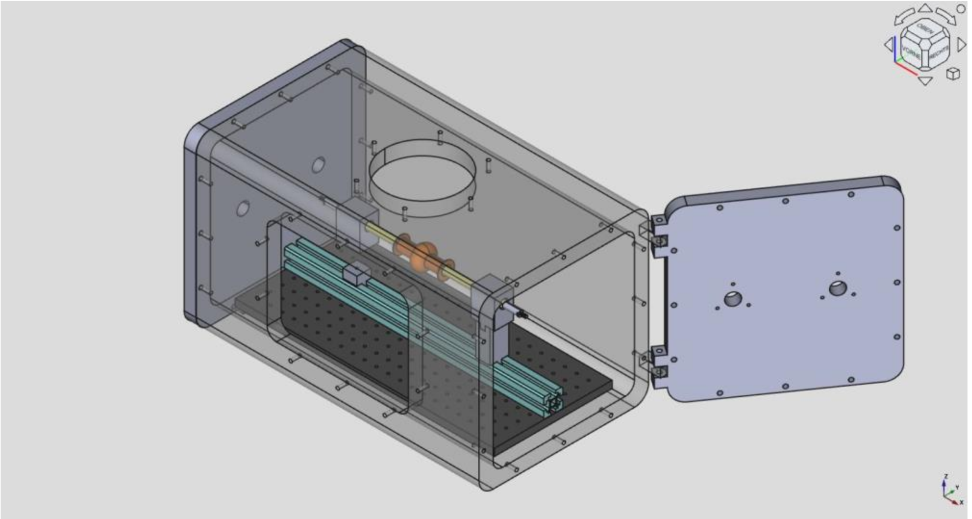
FLA system for 6 GHz cavities

- Piccoli Srl produced 2023 more than 30 seamless 6 GHz Cu cavities for WP9 and FLA project with an optimized process

- **Holding system ready**
- **Vacuum system designed and commissioned**
- **First test planned in June 2024**

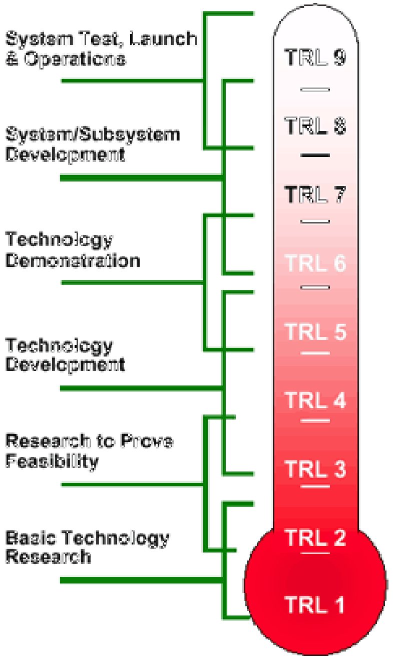


Holding system for the flash lamp and cavity



3D design of the complete system

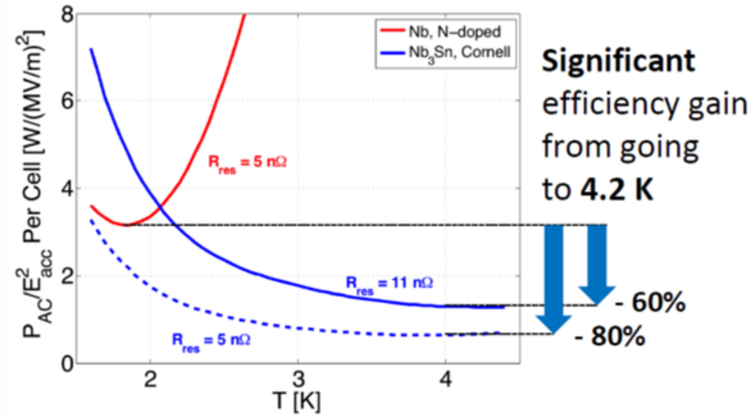
Industrialisation & Environment



- **The TRL remains at TRL 3**

Our technology will significantly **reduce the environmental impact** and **energy-costs** of SRF accelerator technology:

- The goal is to realize SC resonant cavities operating at higher T than bulk Nb **reducing cryogenic power costs by 60%**
- The thermal load and hence the temperature throughout the entire substrate is much lower compared to conventional annealing: **FLA consume less energy (20-30% power reduction (1)**, resulting in a reduction of **CO_2 emissions**



(1) Rovak GmbH experience on Semiconductors

*A **Field Emission Cathode** for a **Travelling-Wave RF gun** for High Brightness Beams in **Industrial** and **Small Research Facility** Settings (FE Cathode)*

T. Lucas, PSI (Switzerland),
R. Jongen VDL ETG (Switzerland)

Commissioning of High-Power Test Stand

- **High Power Test** stand running and conditioning first of two rf photoguns
- **LLRF, safety and interlock system updated**
- **TW gun cells machined**
- **Cathode test stand developed**
- **Final cathodes ordered**

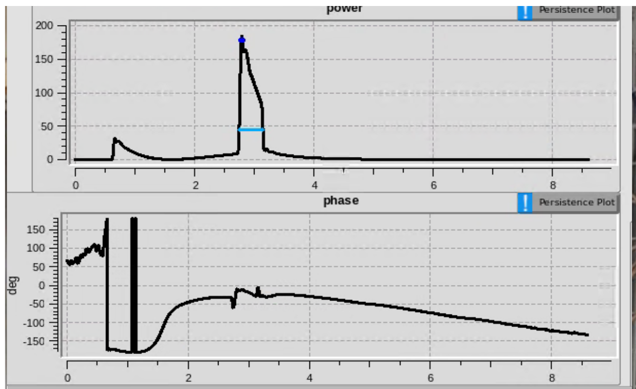


Figure 4: Measurements of the RF pulse into the SW gun from LLRF

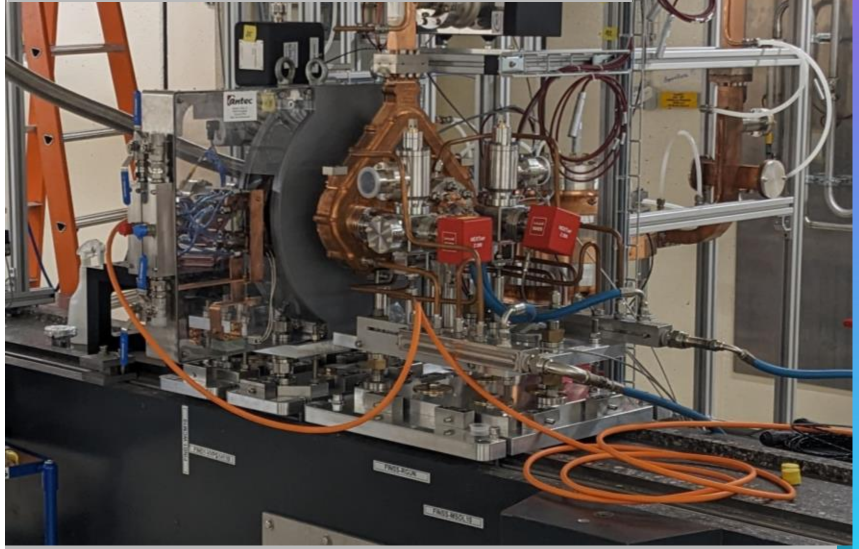


Figure 3: Test stand in Operation

Figure 1: Machined TW gun pieces

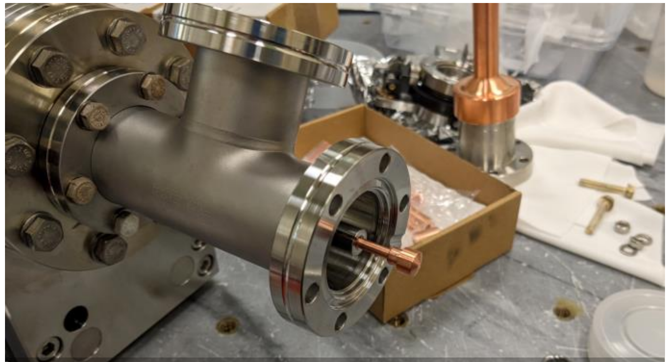


Figure 2: Cathode mount test stand for TW gun

Realisation of TW gun, cathodes & Diagnostics Line

- **Concept for beamline** for energy spread measurements conceived
- **Components for beamline ordered or acquired**
- Aim to **reuse some instrumentation** and **magnetic components from SLS to reduce carbon footprint**

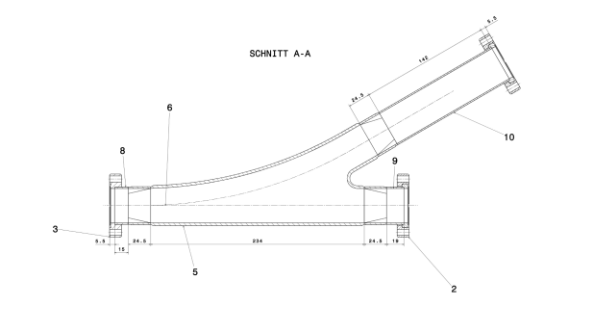


Figure 4: Vacuum chamber for bending magnet

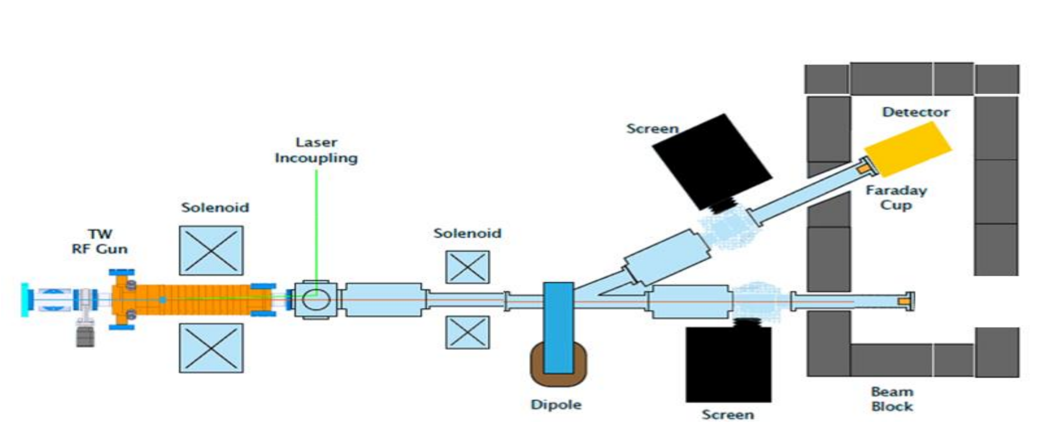


Figure 5: Beamline Layout


Figure 6: Screen and Camera

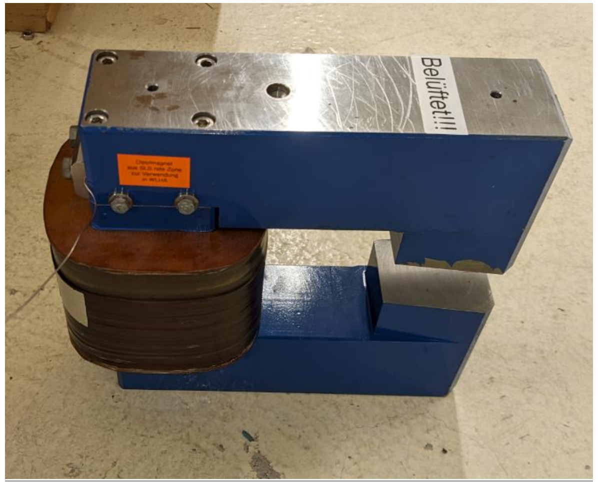
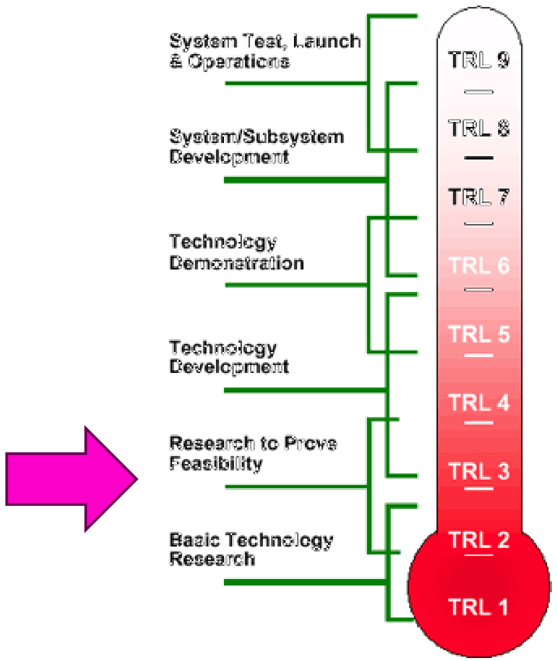


Figure 7: Bending magnet

Industrialisation & Environmental Impact



- **The TRL remains at TRL 3**.
- The cathodes are under manufacture by VDL ETG,
- The gun's components have been machined,
- the beamline concept is ready, and components for this beamline such as dipole, faraday cup and screen are ready or in production.
- A field emission-based travelling-wave (TW) high brightness source can **significantly reduce the power requirements and environmental** impacts of a high brightness electron source. The following are positive environment impacts of field emission TW electron sources:
  - **The removal of the requirement for a high peak power laser** reduces the power consumption. Such lasers have notoriously inefficient plug-to-laser power efficiency.
  - Standing-wave RF guns use isolators to dump reflected power. Such devices currently operate under SF_6 which is not only a potent green-house gas but under the conditions of RF breakdown can generate S_2F_{12} a highly toxic chemical. **TW guns do not require circulators.**
  - For higher energy beams a SW RF gun or DC source will require a booster/bunching section powered by a second klystron-modulator. **TW guns can be designed with more cells to increase the output energy.**

Output

https://doi.org/10.1103/PhysRevAccelBeams.26.103401

Task 4.2 synergy with WP3: Industry engagement

- **Projects** with **most advanced TRL** and **potential** in a **business case study** have been selected
- **Met** with the **representatives** and understood their **interests** in going for **commercialisation**
- **First interview** with a project **performed in March 2024**
- **Other interviews** foreseen in the near future
- **Facilitating new synergy & collaboration between IIF projects**

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

Thank you for your attention

iFAST

Development of Highly Efficient Megawatt Class Cross Field Vacuum Tube Amplifier for Particle Accelerators Driven by a Solid-State Power Amplifier at 750 MHz

Anshu Sharan Singh and Dragos Dancila
(Uppsala University - FREIA)
Industrial partners: Scandinova AB and Exir Broadcasting AB

Project activities planning update

2024

Activities			
	1	2	3
Design, EM Simulation and fabrication			
T1.1 Literature and Design Study on Cross-field Tubes and Related Components			
T1.2 Slow wave Structure (SWS) design			
T1.3 Cold Cathode design			
T 1.4 Computational model for Magnetic field design			
T 1.5 Beam wave interaction study of Crossfield amplifiers			
T 1.6 Fabrication and Metrological Inspection of SWS			
T 1.7 VSWR testing			
Deliverable (Computational model and SWS of CFA)			

Extensive design, modelling and numerical simulations

Project activities planning update

Activities	2024											
	1	2	3	4	5	6	7	8	9	10	11	12
Design, EM Simulation and fabrication												
T1.1 Literature and Design Study on Cross-field Tubes and Related Components												
T1.2 Slow wave Structure (SWS) design												
T1.3 Cold Cathode design												
T 1.4 Computational model for Magnetic field design												
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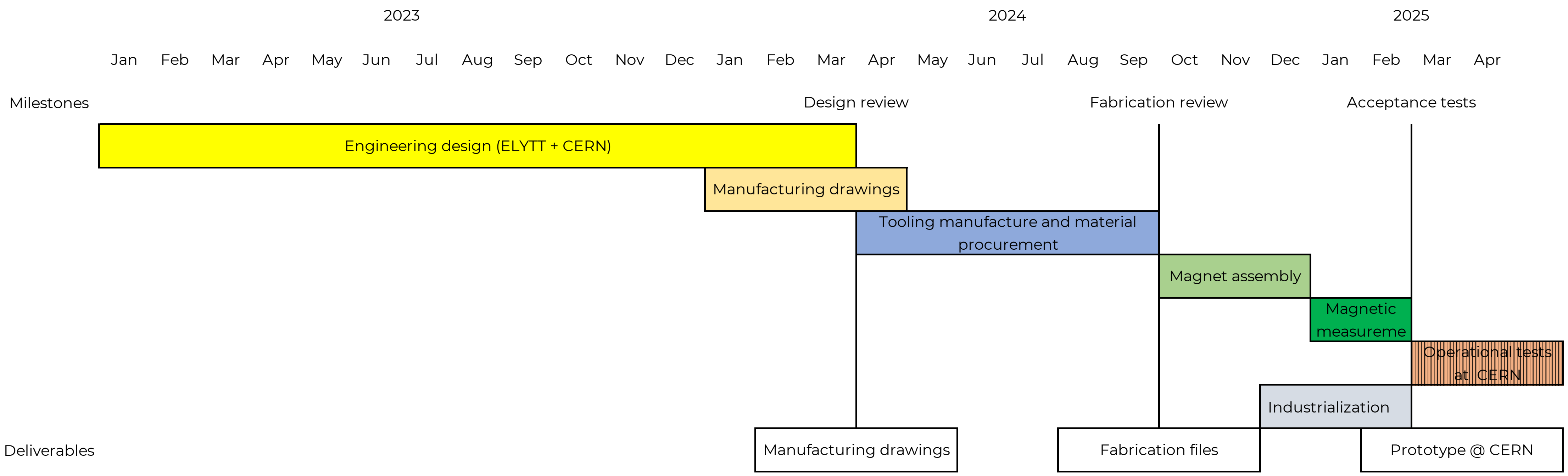
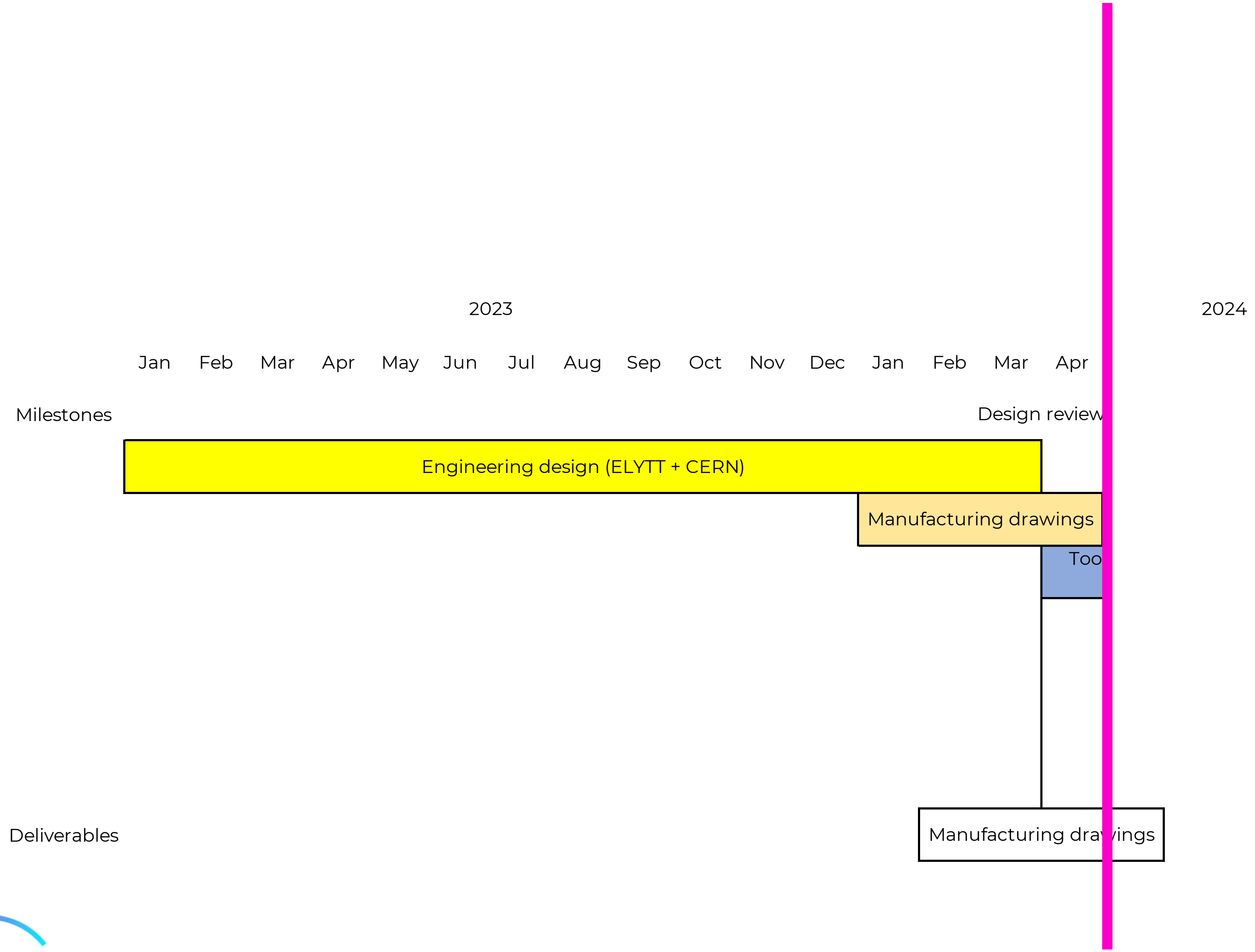
T 1.6 Fabrication and Metrological Inspection of SWS												
T 1.7 VSWR testing												
Deliverable (Computational model and SWS of CFA)												

PM4HEK updated planning



PM4HEK updated planning



engineering design +
numerical simulations +
technical drawings

Hvac - Demonstration of Additive Manufacturing for Large and Complex Shaped Vacuum Chambers by Plasma Metal Deposition (PMD®)

Dr. Carlos Belei
Project Engineer – RHP Technology GmbH

Dr. Erich Neubauer

Managing Director – RHP Technology GmbH

+ remaining activities in 2024

2023

Work package	Partner	M01	M02	M03	M04	M05	M06	M07	M08	M09	M10	M11	M12
WP1 - Design	**RHP, SBI**												
WP1.1 - Design of vacuum chamber	RHP, SBI												
WP1.2 - Tool path generation	RHP, SBI												
WP1.3 - Machine adaptation	SBI												
WP2 - Manufacturing	**RHP**												
WP2.1 - Manufacturing of subsize model	RHP												
WP2.2 - Manufacturing of full-size model	RHP												
WP2.3 - Finishing of vacuum chamber	RHP												
WP3 - Testing	**RHP**												
WP3.1 - Testing of vacuum chamber	RHP												
WP3.2 - Technology assessment	RHP												
WP3.3 - IP analysis and IP protection	RHP												

design + manufacturing + testing

Activities yet to be performed/completed
Based on the original work plan

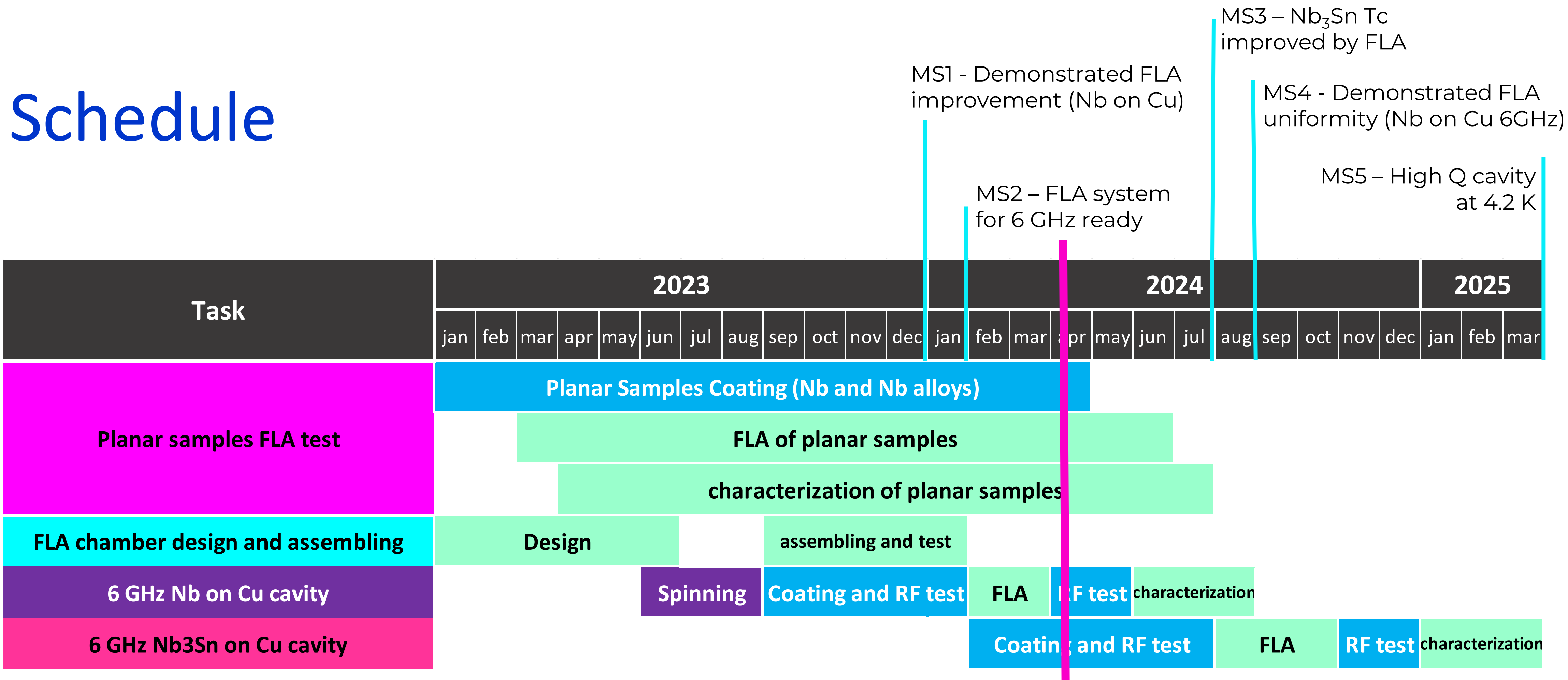
Machining of subsequent flanges [**RHP**]
Side flanges still to be machined;
ETA: April 2024.

Evaluation of sub-scale model [**RHP**]
Vacuum test with more powerful pumping systems (~ 10^{-8} mbar); Requires external subcontracting;
ETA: May 2024.

Technology assessment [**SBI/RHP**]
Economical viability evaluation for the construction of new machine (market, demand, etc);
ETA: May 2024.

IP: assessment of possible patent application together with patent attorney;
ETA: May 2024.

Schedule



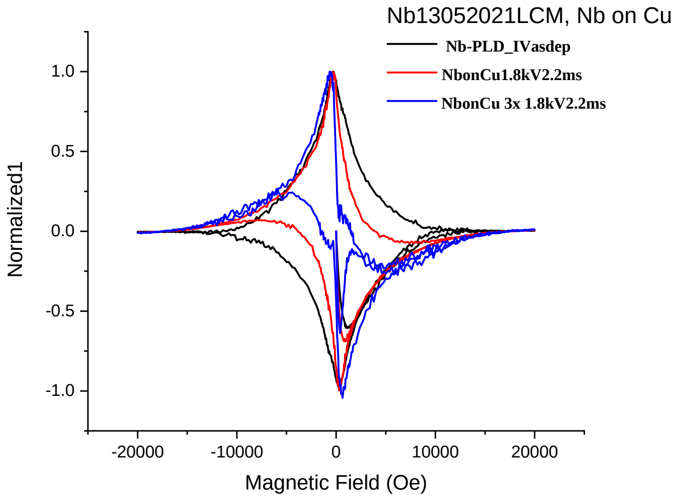
- Sample test on track (MS1)
- Delay of 3 months on MS2

HZDR HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF
INFN
PICCOLI srl

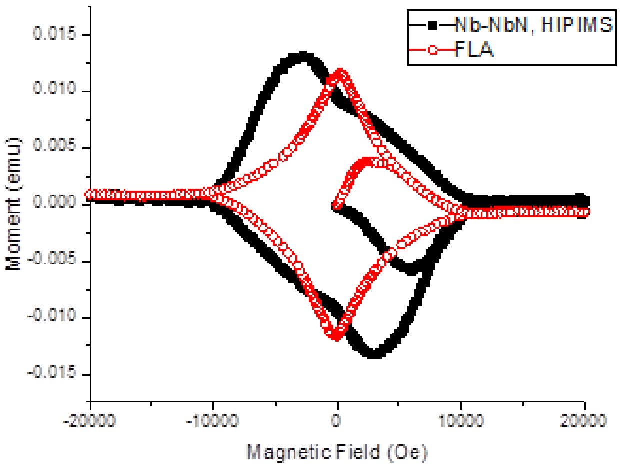
iFAST

First results on planar samples

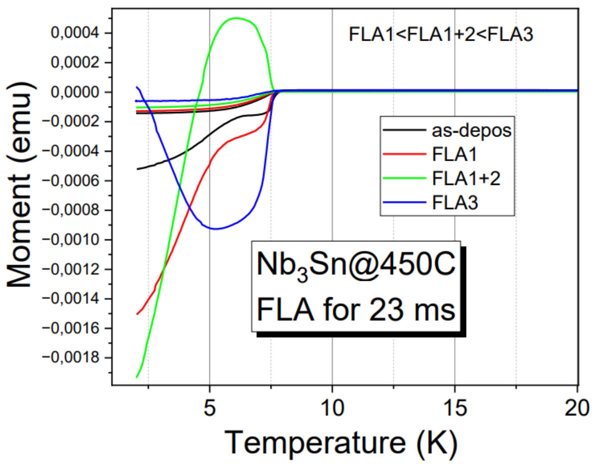
- On Nb and NbN coatings FLA produce a narrower hysteresis curve *(material crystallinity improved)*
- No noticeable effect on Nb_3Sn coatings deposited at 450 °C. Waiting characterization from High T Nb_3Sn samples (in progress)



Nb on Cu



NbN on Cu



Nb_3Sn on Cu

Commissioning of High Power Test Stand

- High Power Test stand running and conditioning first of two rf photoguns **(relates to Deliverable 2 and 3).**
- LLRF, safety and interlock system updated to bring test stand up to necessary performance level **(Milestone 2 achieved).**
- TW gun cells machined.
- Cathode test stand developed for cathode mounting tests with FE cathode dummies. Final cathodes ordered **(relates to Deliverable 1)**.

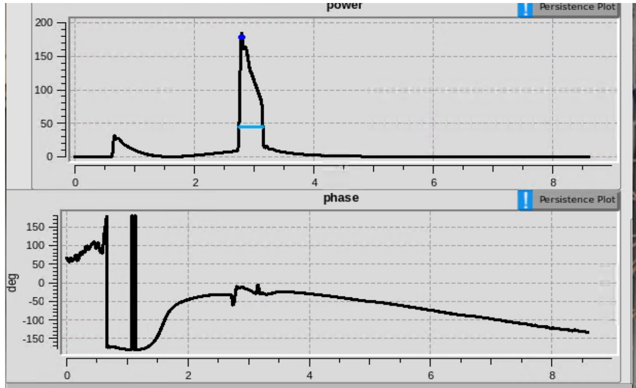


Figure 4: Measurements of the RF pulse into the SW gun from LLRF

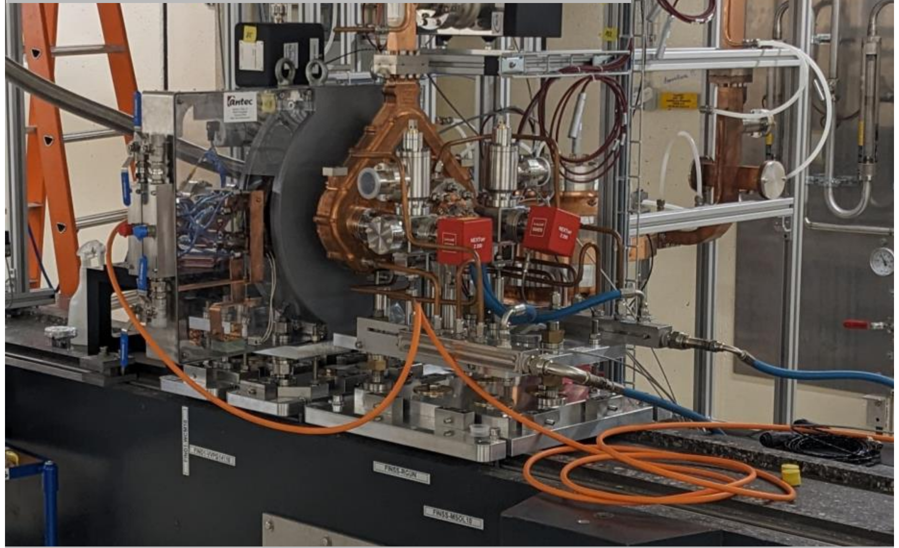


Figure 3: Test stand in Operation


Figure 1: Machined TW gun pieces

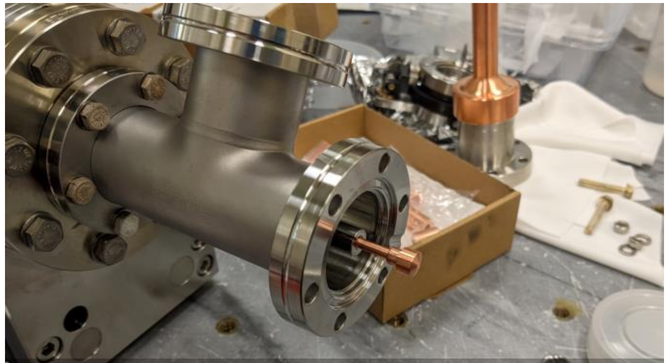


Figure 2: Cathode mount test stand for TW gun