INFN

Plasma Electrolytic Polishing

for SRF

Eduard **Chyhyrynets**

11th International Workshop on Thin Films and New Ideas for Pushing the Limits of RF Superconductivity

TFSRF2024

16 – 20 September 2024

Finanziato dall'Unione europea NextGenerationEU

Ministero dell'Università e della Ricerca

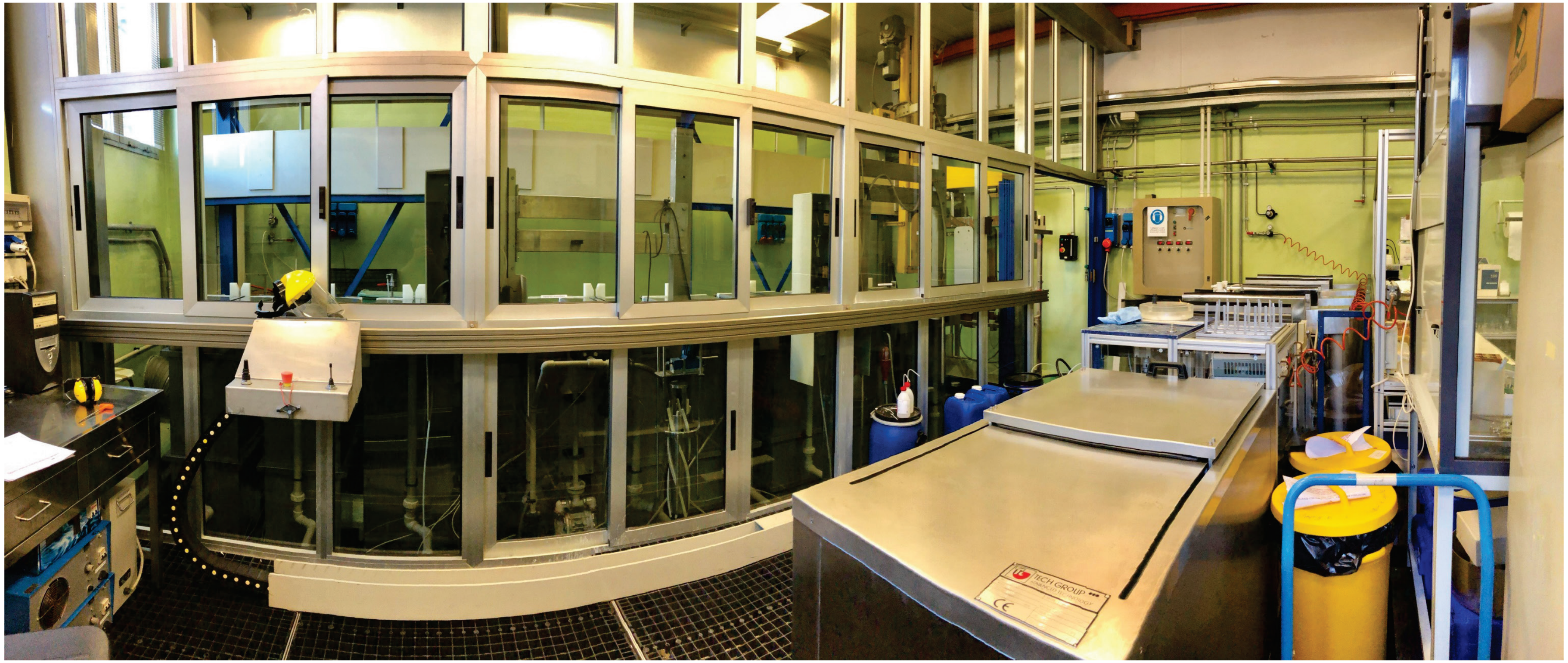
Italiadomani PIANO NAZIONALE DI RIPRESA E RESILIENZA

NQSTI National Quantum Science and Technology Institute

Scaling PEP for 1.3 GHz cavities

PEP Validation

QWR Legnaro Plant



Motivation

➢ **Cu substrate plays a fundamental role in SRF performances**

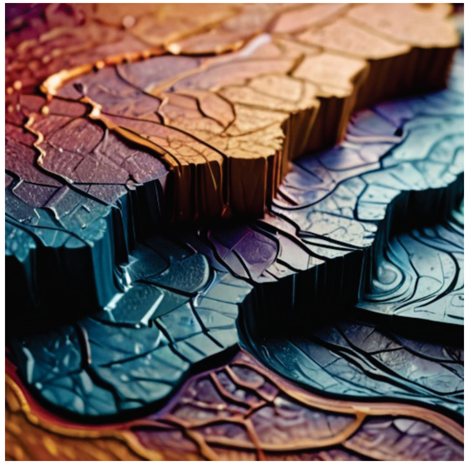
$$Q_0 = \frac{G}{R_s}$$

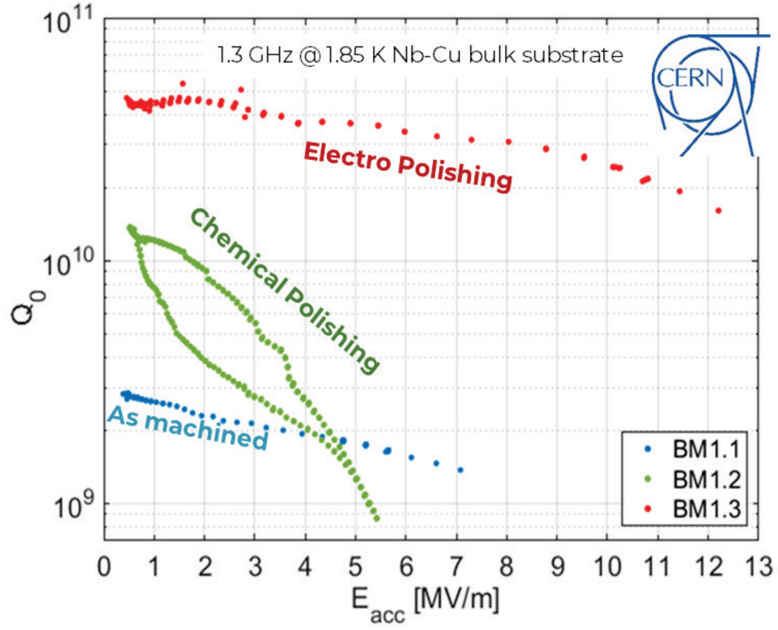
Cavity geometry

Surface resistance

1. High SRF performance **requires roughness and defects reduction**

2. Thin Film deposits **replicate the substrate**





L.Vega Cid, TTC meeting (elaborated)

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Limitations of EP

- **Concentrated acids** -> Risks
  In case of Nb -> use of HF.
- **Slow polishing rates** -> tens of hours or days
- **Requires prepolishing** (CBP, tumbling, ecc)

HF

Nb SRF cavity polishing requires hydrofluoric acid (HF)

- *HF is an extremely dangerous and poisoning acid*
- *Serious workers hazard risks*
- *Expensive procurement and disposal*
- *Expensive infrastructure for safe handling*

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Basics of PEP

- **No Acids** in the chemical bath!
- **No HF** for Nb!
- Easier storage
- Easier and cheaper wastes proceeding

Green

Diluted water solutions, enviromentally friendly

Efficiency

Equal thickness removal yield lowest roughness among competitors

PEP > BCP > EP
PEP > SUBU > EP

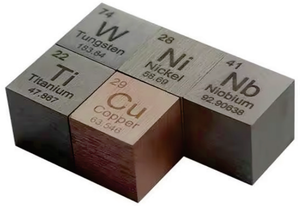
5-30x times **faster** than EP!

Fast

The fastest non-destructive polishing

Versatility

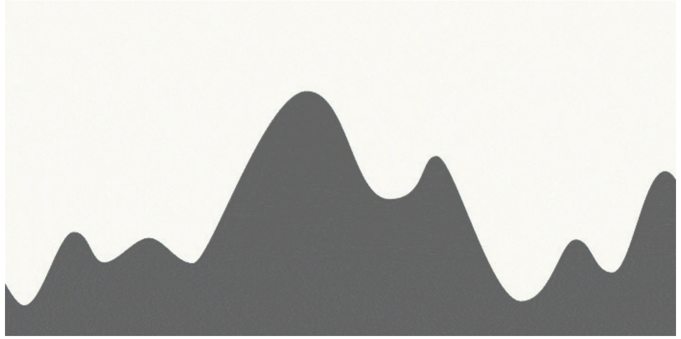
Less sensitive to the cathode shape!
Additive manufacturing compatible

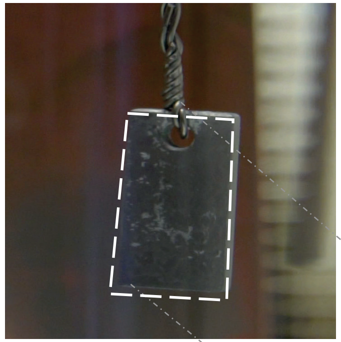


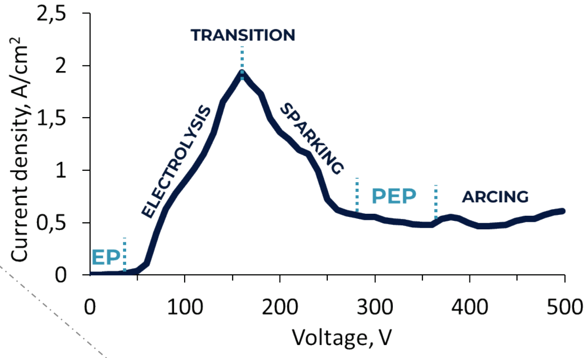
Both micro and macro **roughness is improved significantly**

Ra ~ 8 nm!!!

Plasma Electrolytic Polishing



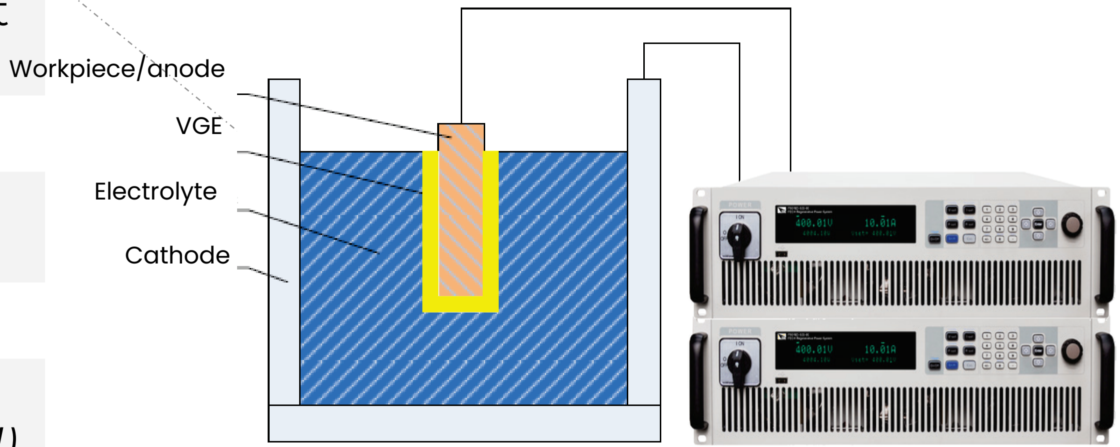




Vapor Gas Layer

Electrochemical method of polishing
A special case of anodic dissolution

	EP	PEP
Bath	Concentrated acid solutions	Diluted water-salt solutions
Area **chatode: anode**	1:1	10:1
Working voltage	2-25 V	260 – 340 V
Current density	0,03 A/cm²	0,1-0,8 A/cm²
Temperature	4-60 C° *(lower is better)*	70-90 C° *(high T is required)*



LNL Timeline

2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028

4/2019
PEP R&D started

4/2019
First Cu Planar sample successfully polished by PEP

2/2021
First Nb Planar sample successfully polished by PEP

5/2022
PEP Nb Patent Pending

1/2023
PEP Cu Patent Pending

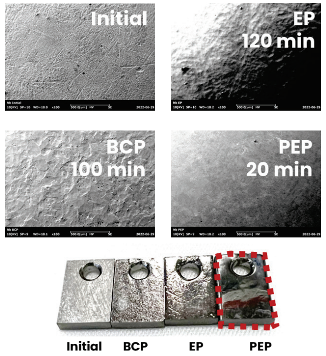
5/2023
6 GHz cavity polished by PEP

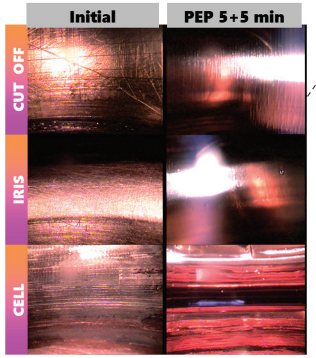
11/2023
PEP Nb Patent Approved

2024
First Cu 1.3 GHz polished by PEP

PEP

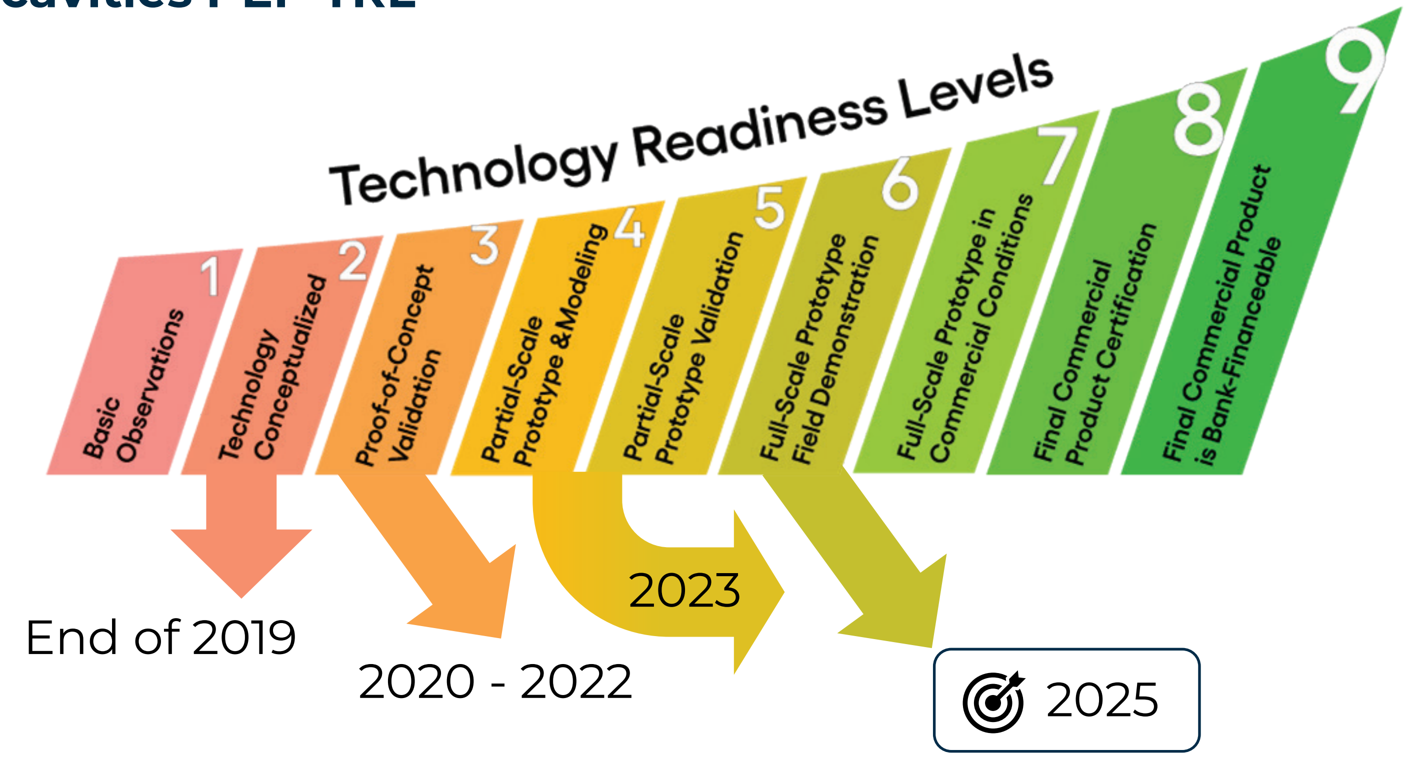
1.3 GHz cavity polished by PEP Coated and RF tested @CERN





TRL Evolution

Cu Elliptical cavities PEP TRL



- Main goal to PEP a 1.3 GHz Cu cavity
- Remove 150 – 200 μm

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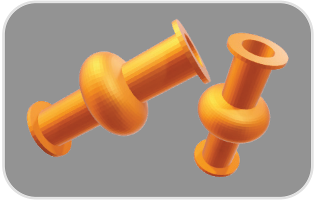
Scaling challenges

High current densities (Power modes)

Technological scale (volume + surface area)



Process substrate orientation

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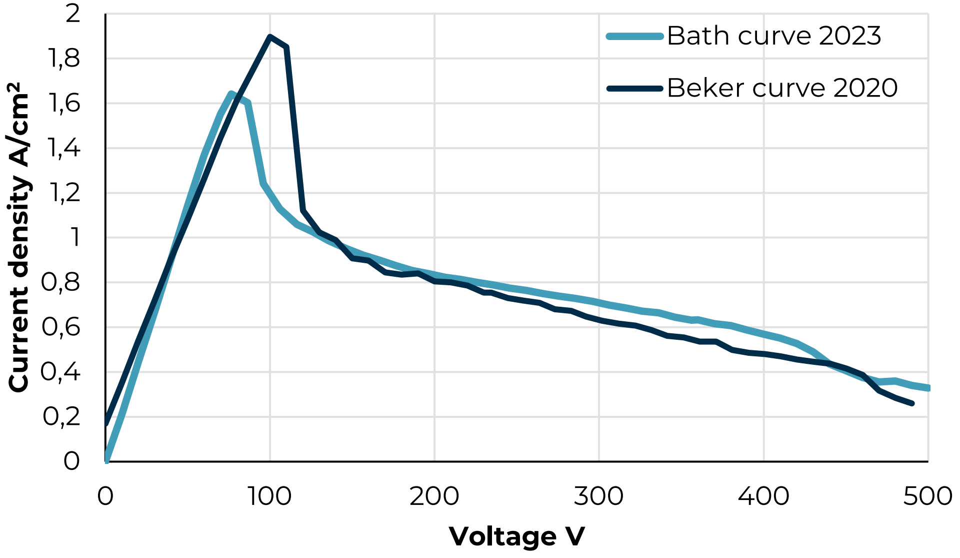
Current density

0,1 – 0,6 A/cm²

40 cm²
in **30 L** bath

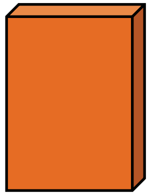
12 cm²
in **5 L** bath

Current/Voltage curve Cu;



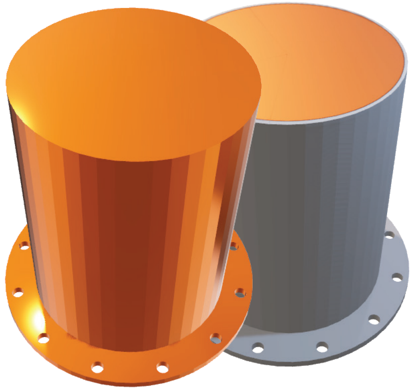
Similiar / Same behaviour after scaling

Current density



5 cm^2

3 A

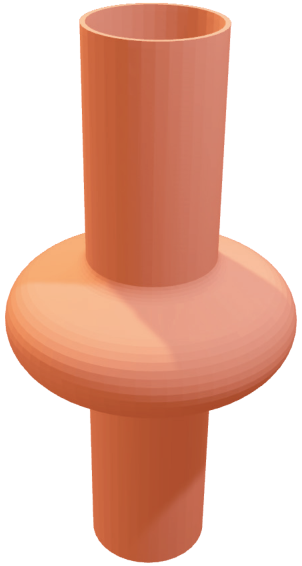


150 cm^2
*external

90-150 A

90 cm^2
*internal
6 GHz

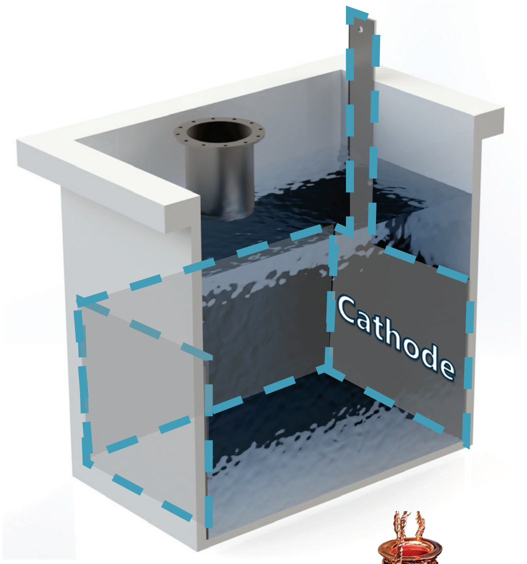
35-45 A



1400 cm^2
*internal
1.3 GHz

90-180 A

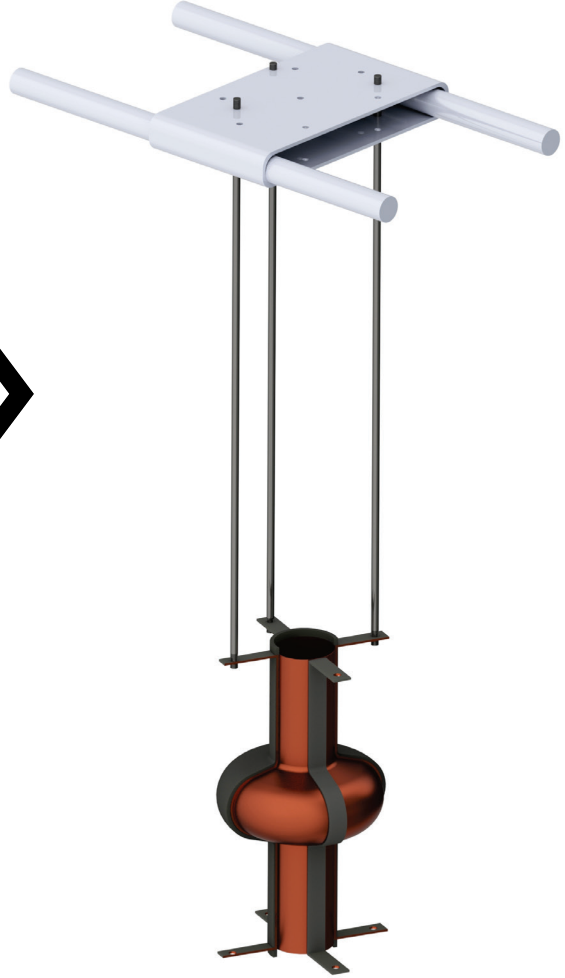
1.3 GHz Adoption



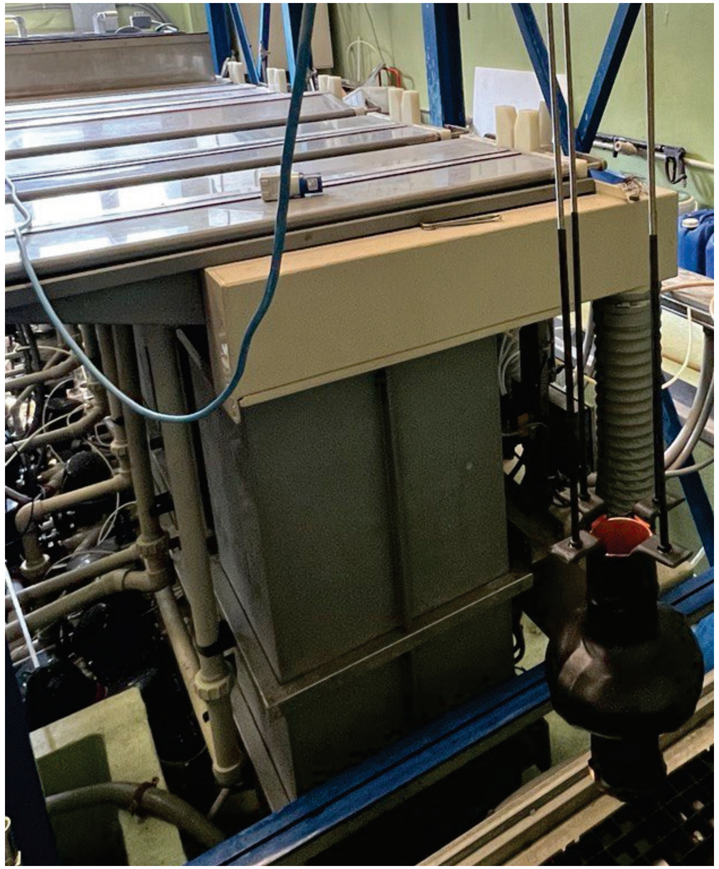
30 L

6 GHz Cu validation

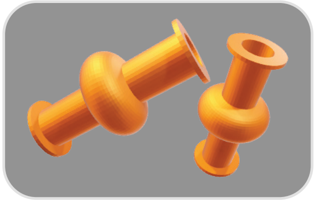
E. Chyhyrynets et. al @ SRF'23



No internal cathode!



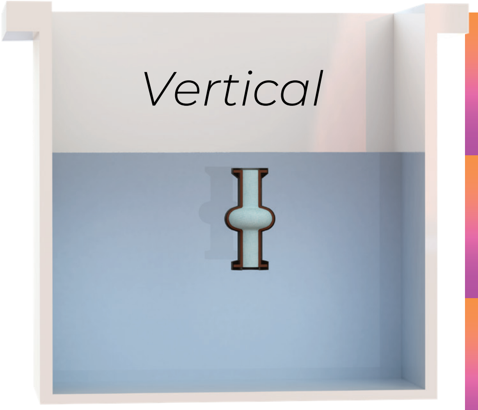
300 L
QWR plant @ LNL

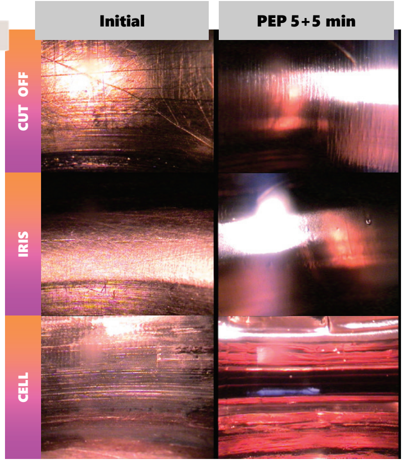


Orientation

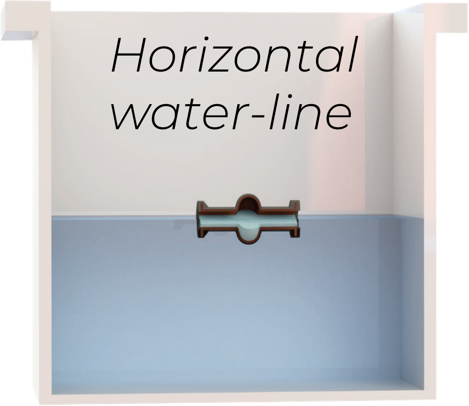
From 6 GHz Cu experience

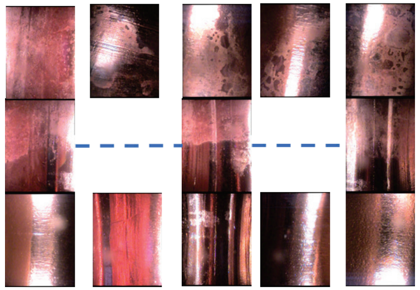
1





2





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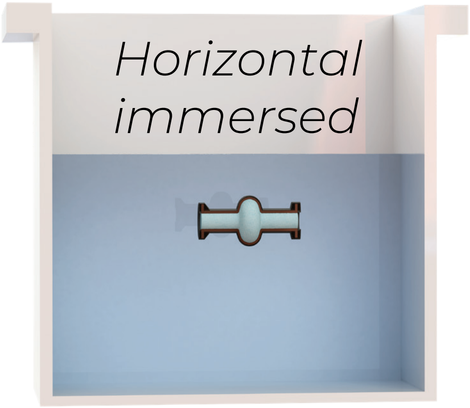
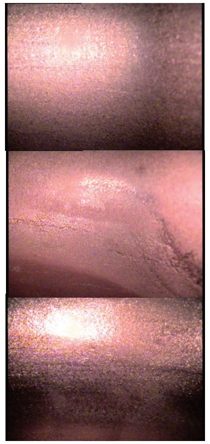
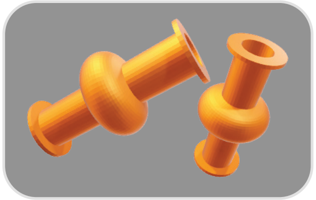
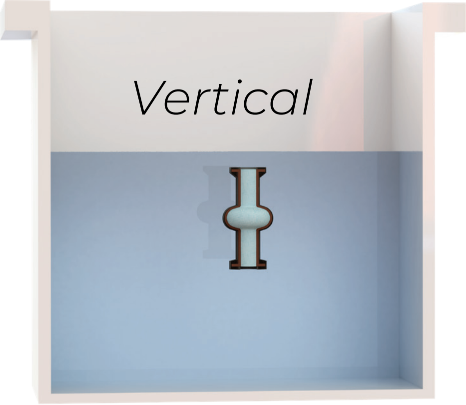






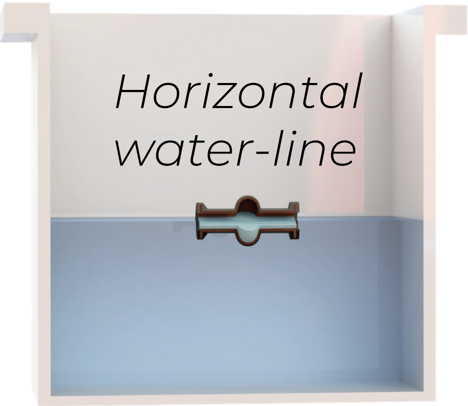
Orientation

1



- **Simplier** setup
- All surface polishing
- Possible non-uniformity
- Higher current regimes
- Needs rotation

2



- **Uniform** polishing
- **Half currents** regime
- Water line control during process
- Rotation mechanism
- Lower speeds
- Stains of oxidation
- Longer process

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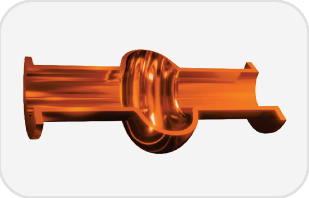
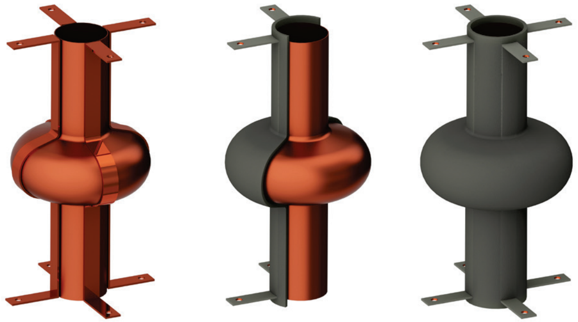
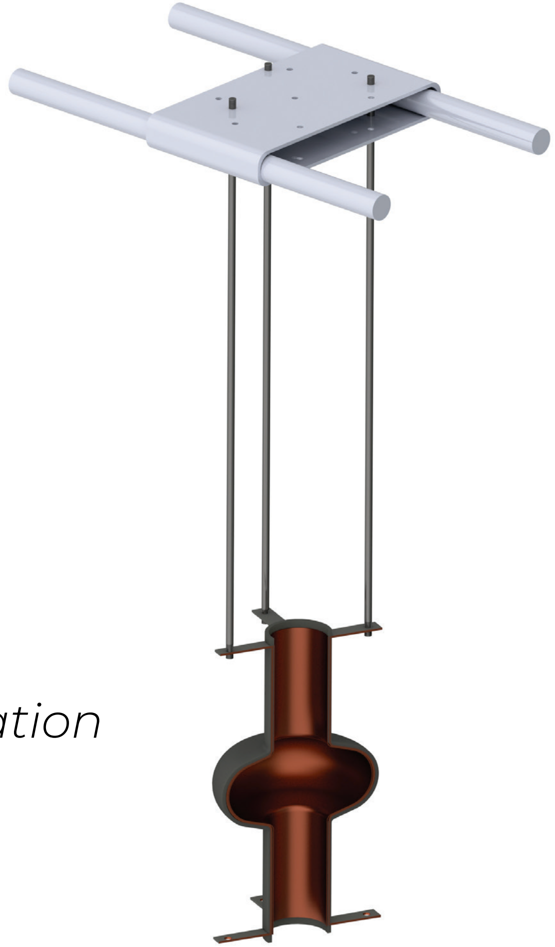


Validation

1.3 GHz cavity sample

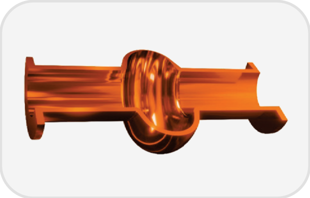


External isolation



Process parameters

Voltage 300 V
Surface area 1400 cm^2
Currents 90-190 A (0,06 – 0,13 A/cm^2)

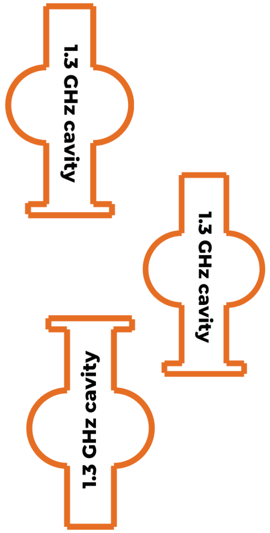


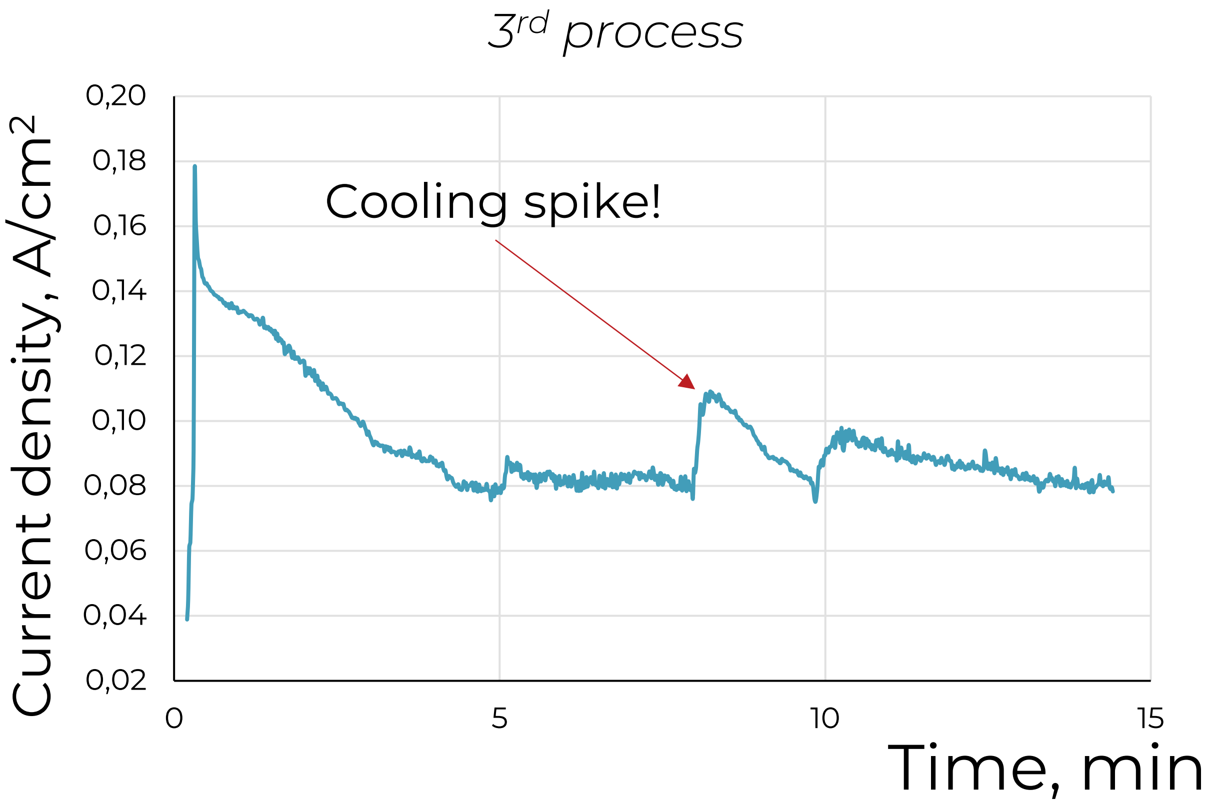
Validation

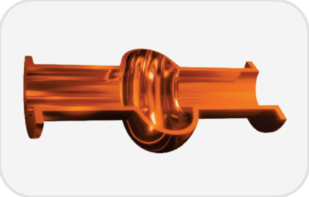
1.3 GHz cavity sample

3 process

#	Time	RR	Thickness
1	15 min	5,1 µm/min	79 µm
2	6 min	5,4 µm/min	35 µm
3	14,5 min	5,2 µm/min	75 µm
TOT	**35,5 min**	**5,4 µm/min**	**190 µm**

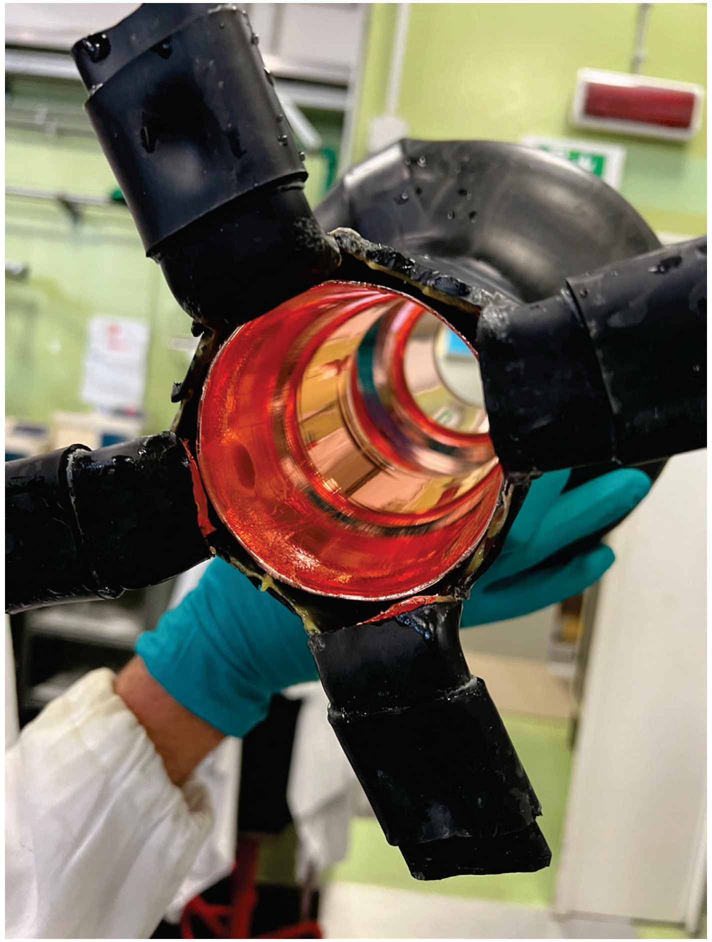






Resulting surface

After 3° process



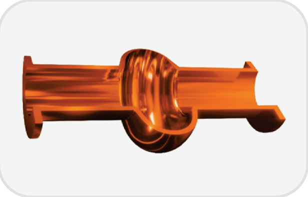
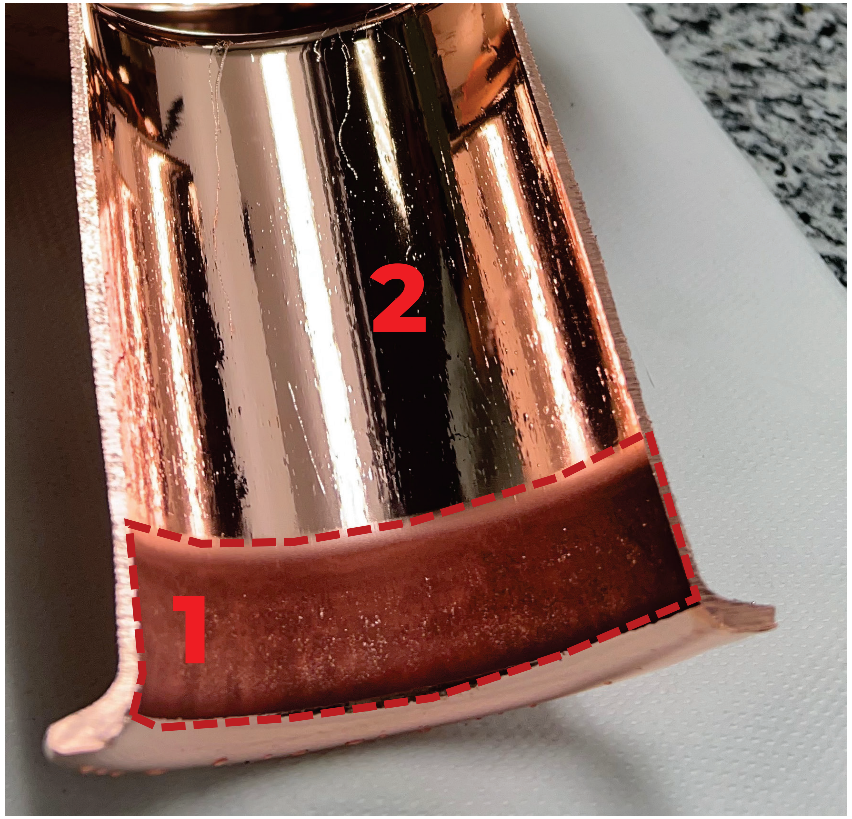


Photo + Issues

1.3 GHz cavity sample



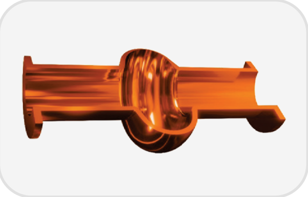
1. **Etched zone**
2. **Glue Residue Marks**

1. Unclear nature
2. Sometimes appear
3. To be studied more

Heat-shrink tubing use

💡 Plastic (PVDF, ecc) isolation alternative

💡 Thermoshrinking isolation <u>without</u> glue



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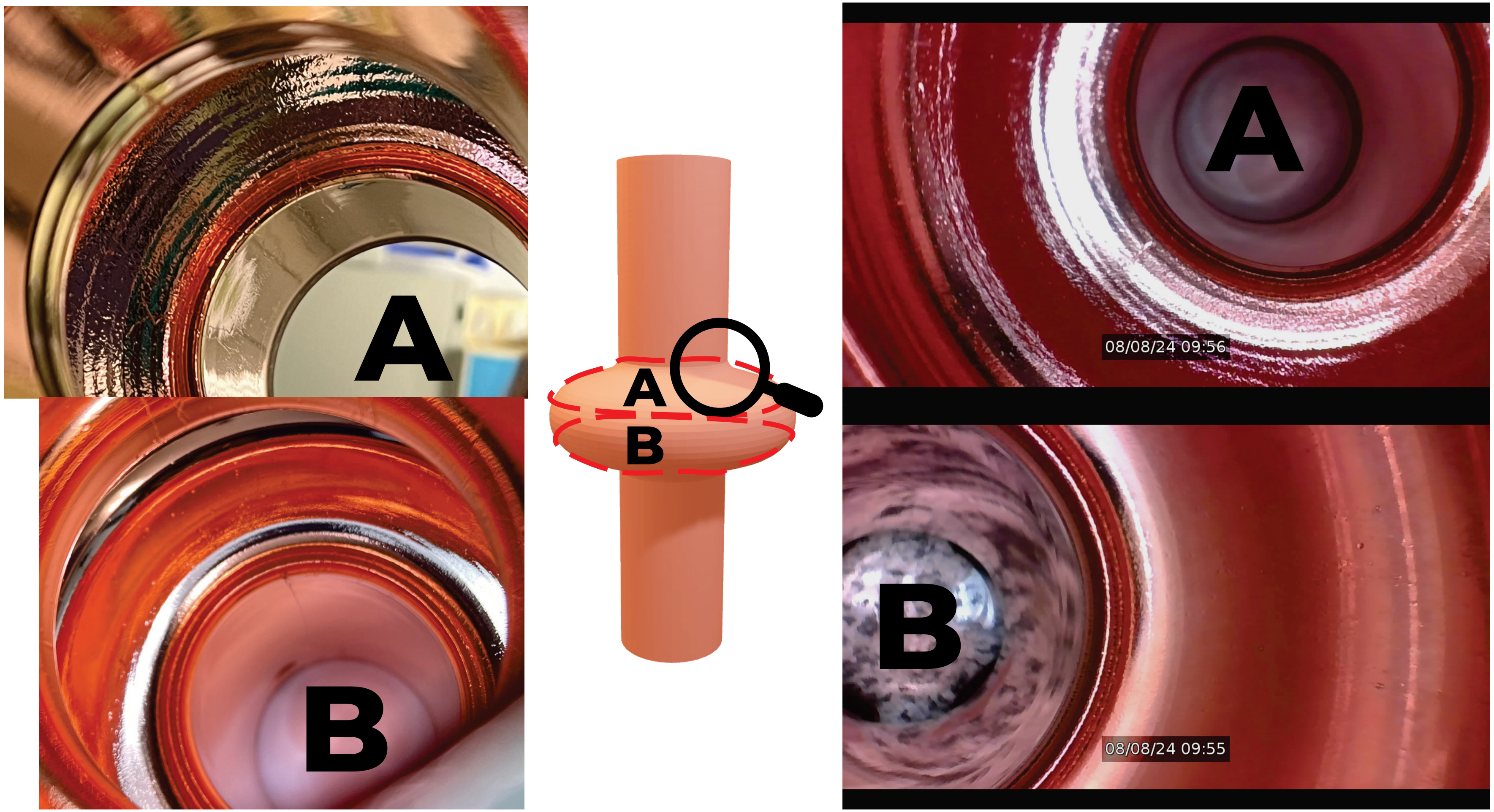
1.3 GHz cavity sample



Energy consumtion

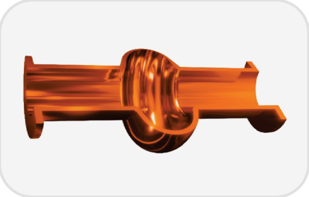
1.3 GHz cavity sample

	EP		PEP
A, Area	500 cm^2	1400 cm^2	
V, Voltage	4 V	18 V	**300 V**
i, Current density	0,02 A/cm^2	0,02 A/cm^2	**0,07 A/cm^2**
PR, Polishing rate	0,16 µm/min	0,25 µm/min	**5 µm/min**
Time, τ to remove 200 µm	20h:50min	13h:18min	**0,66 h** (40 min)
P, Total Energy	P'=V*i*A*τ		
	0,67 kwh (*1,87 kwh'*)	2 kwh	**22,4 kwh**
Ratio	0,9 x	1 x	**11,2 x**
	QWR @LNL	*1.3 GHz @CERN*	*1.3 GHz @LNL*

Not included:

- **Cooling** for EP
- **Pre-heating** water PEP
- **Heat loss**

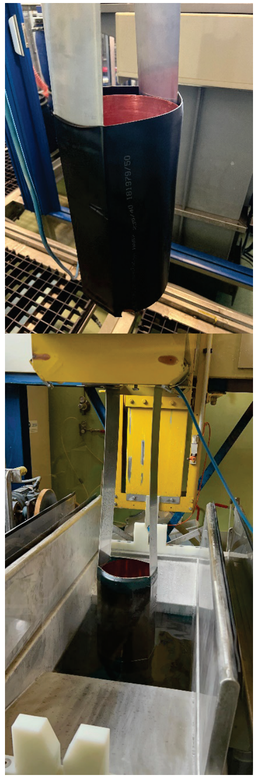
Ferreira et. al
https://dx.doi.org/10.2139/ssrn.4682212



Proof of concept

Pushing the limits

Surface area >> 1.3 GHz



Process parameters

Voltage 300 V
Surface area 2350 cm2
Time 7 min
Current 150-160 A (0,06 – 0,07 A/cm^2)

	Expected	Meusured
Δm, g	80	**69**
δ, μm	40	**32**
PR, μm/min	5	**4,6**
I, A	220	**150-160**
i, A/cm^2	0,08	**0,06 – 0,07**

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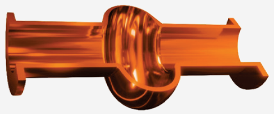
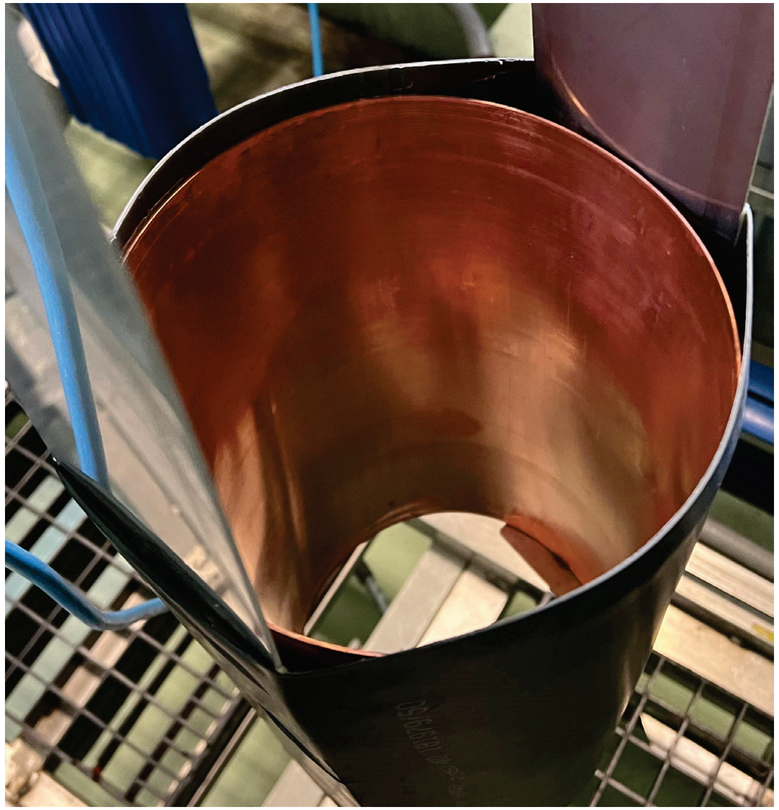
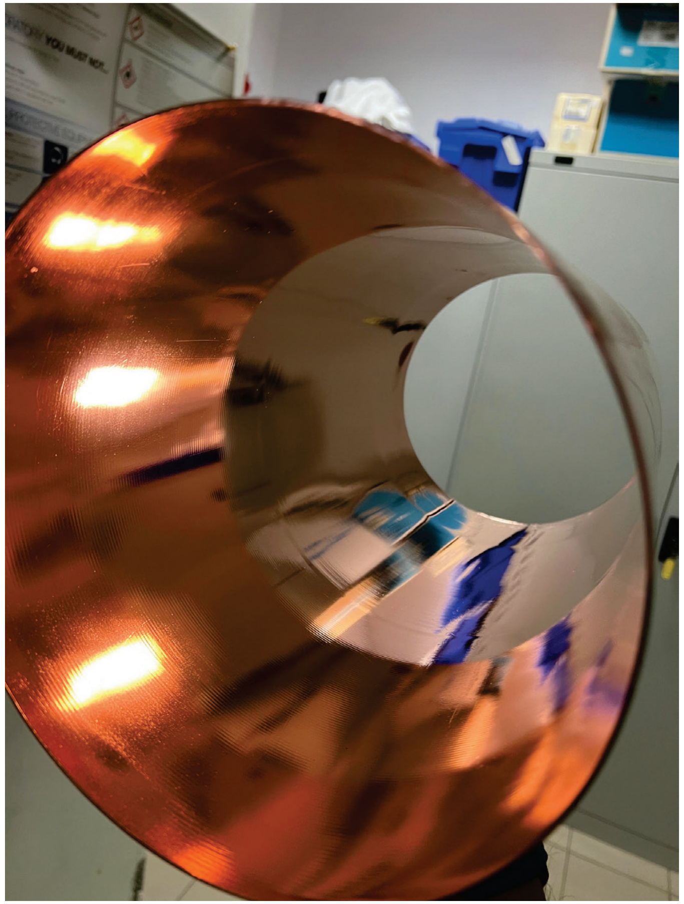
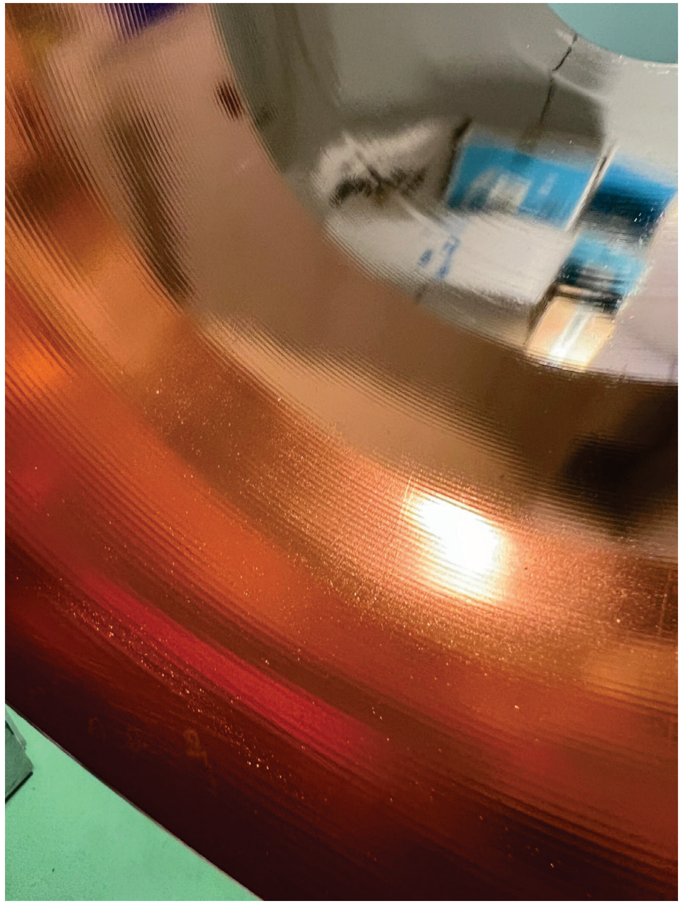


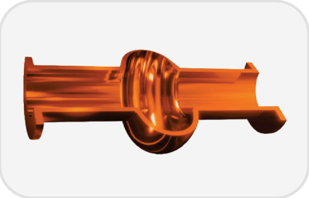
Proof of concept

Pushing the limits



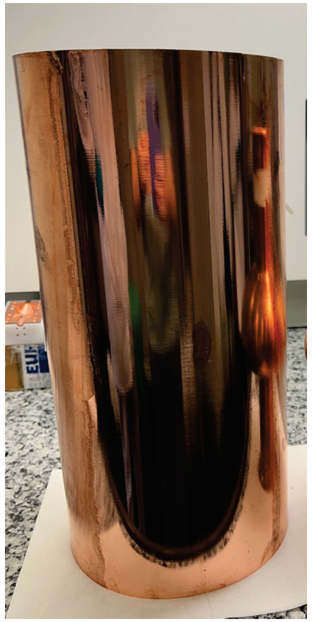






Proof of concept

Can we push more? 400 MHz ?



400 MHz ?

expected

	Cylinder	400 MHz
Area, cm^2	2200	**12 000**
PR, µm/min	4,6	**4**
I, A	150-160	**600 A**
i, A/cm^2	0,065	**0,055**

PEP

Conclusions

- First **successfull demonstration** of 1.3 GHz Cu **PEP**
- Polishing rate **5 µm/min**
- **11x higher** total **energy** consumtion
- PEP can be scaled even further.

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Thank you for your attention!