FCC

LAYER BY LAYER:

Additive Manufacturing Strategies for the FCC-ee Vacuum System with Focus on the Bake-Out System

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Agenda

BOS – Bake-Out System

- Key Requirements and Constraints
- Thermal Spraying Technologies
- Materials Selection
- Track Layout Considerations
- Testing of Coatings
- Scale-Up & Manufacturing Integration

SRA – Synchrotron Radiation Absorber

BPM – Beam Positioning Monitor Sockets

BOS – Key Requirements and Constraints

thin

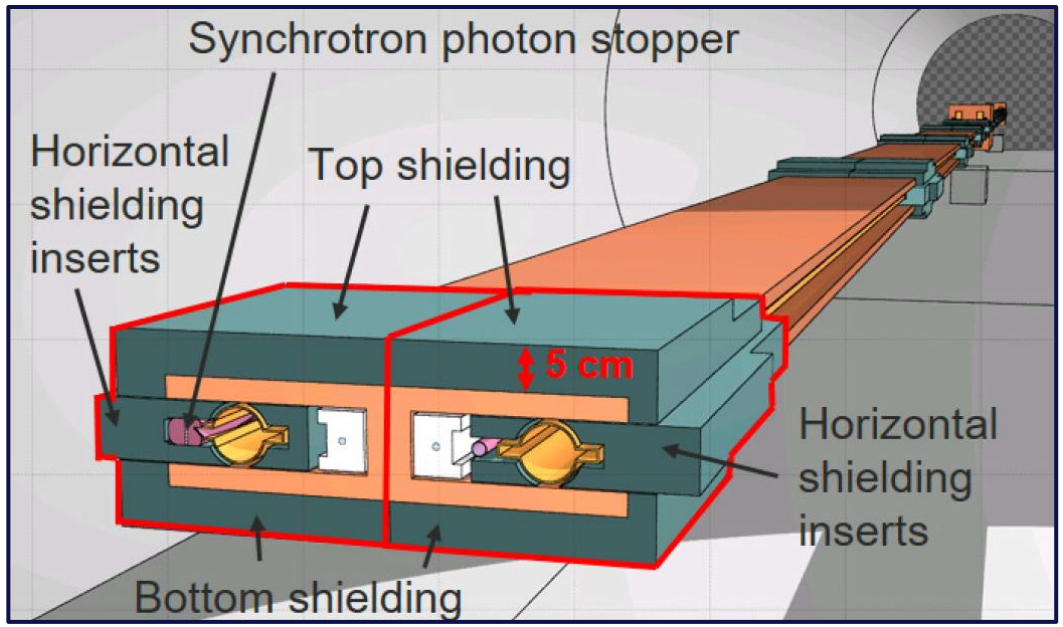
radiation hardness

non ferromagnetic

lifetime durability

RT – 230/250°C

cost efficiency



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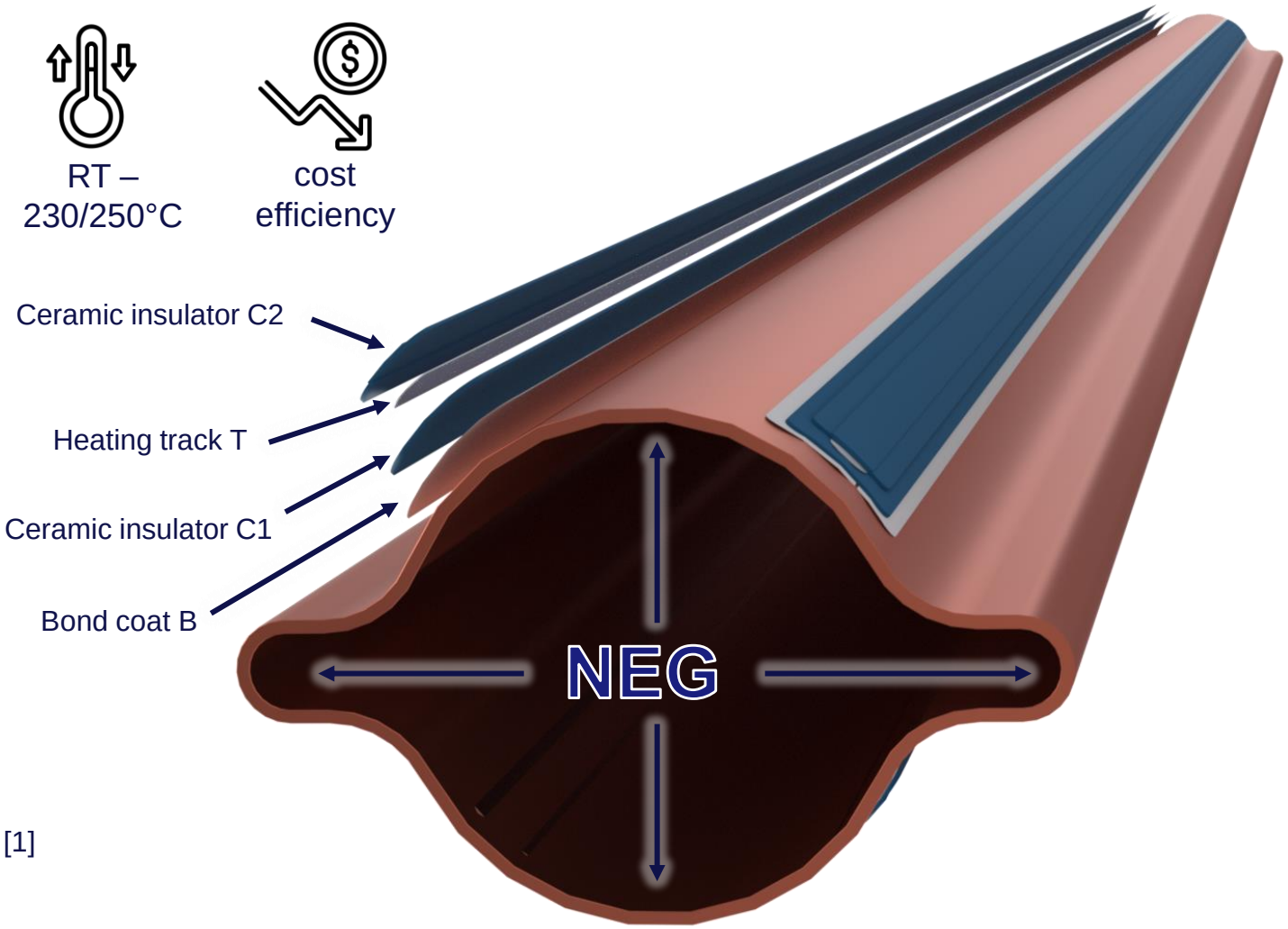
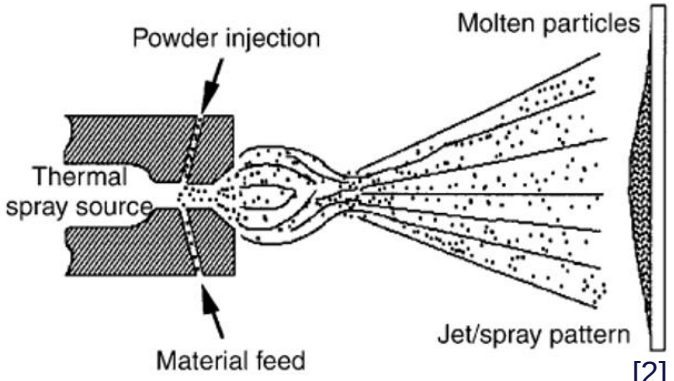


[1] M. Benedikt, J. Gutleber, L. Ulrici, and T. P. Watson, 'Future Circular Collider Feasibility Study Report Volume 3: Civil Engineering, Implementation and Sustainability', CERN Document Server, 2025. doi: 10.17181/CERN.I26X.V4VF.

BOS – Thermal Spray Technologies

Atmospheric Plasma Spray (APS):



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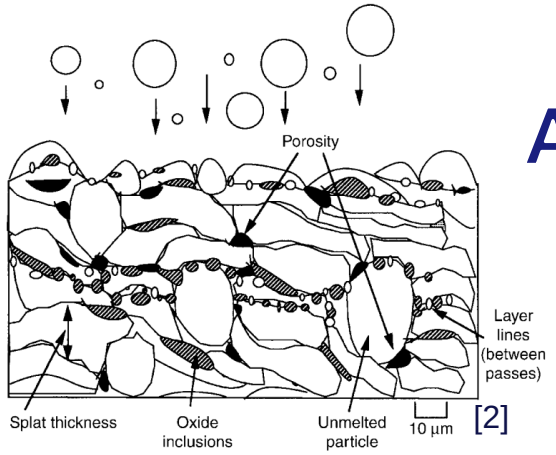

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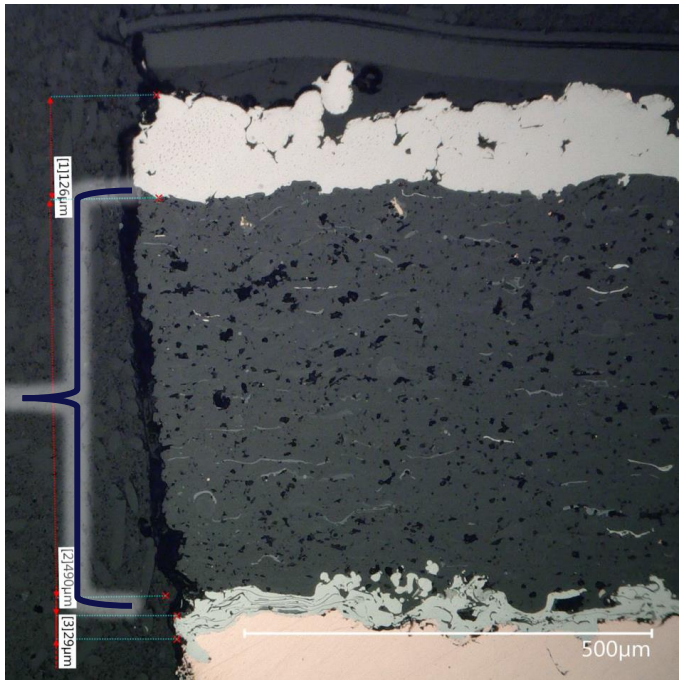
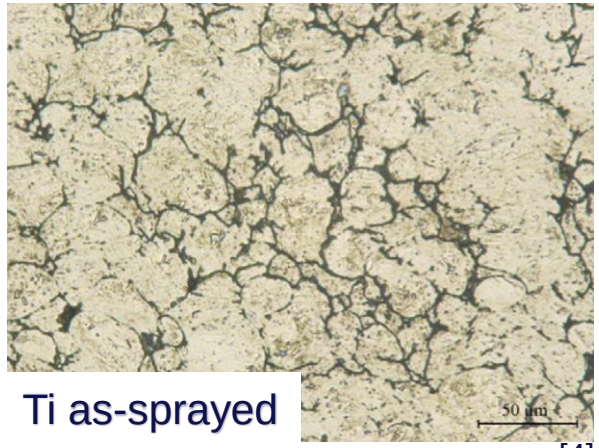
APS



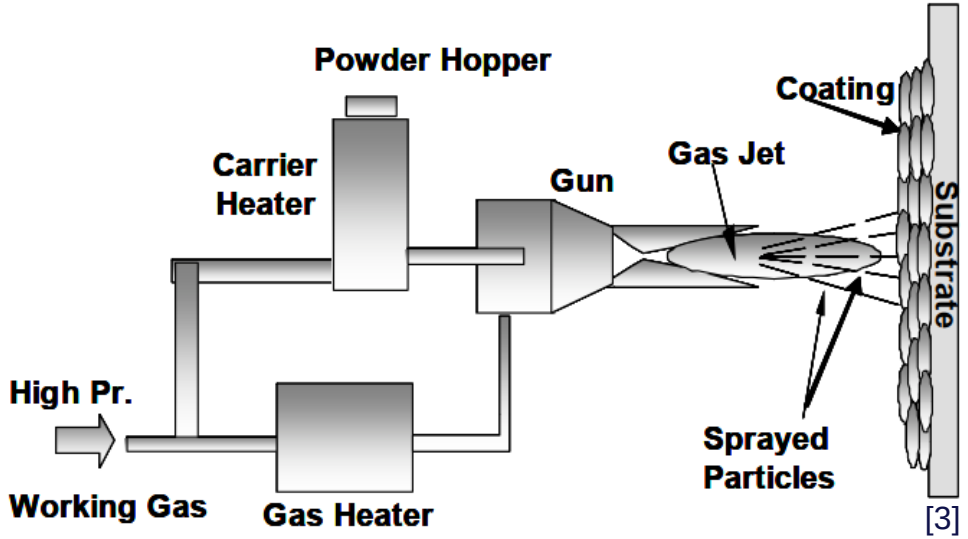
Cold Spray:



Ti as-sprayed

[4]

} Cold Spray



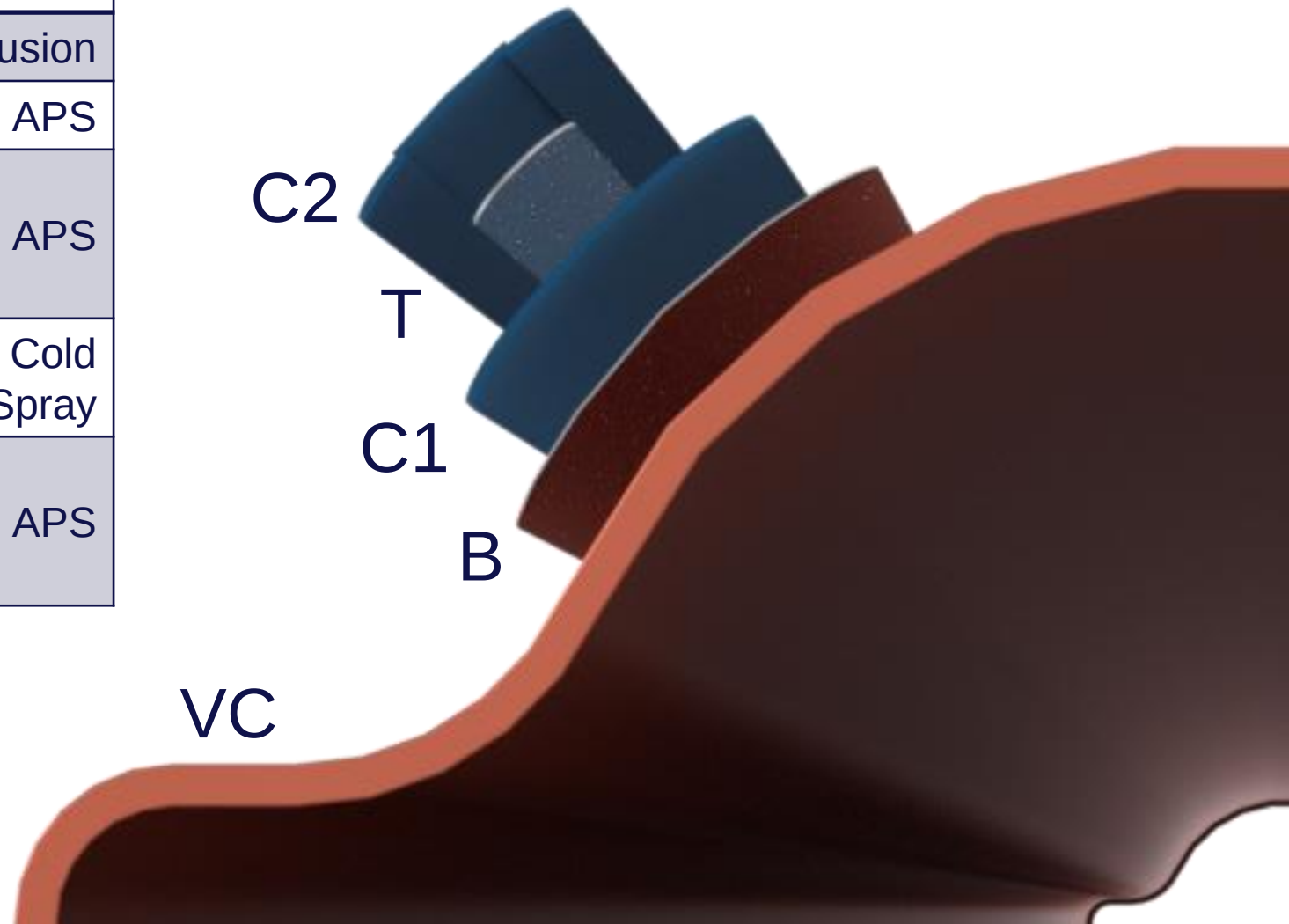
[3]

[2] Jr. Tucker Robert C., *ASM Handbook: Thermal Spray Technology*. ASM International, 2013. doi: 10.31399/asm.hb.v05a.9781627081719
[3] J. Karthikeyan, Industries, and Inc, 'Development of oxidation resistant coatings on grcop-84 substrates by cold spray process', 2007.
[4] R. Huang, M. Sone, W. Ma, and H. Fukanuma, 'The effects of heat treatment on the mechanical properties of cold-sprayed coatings', *Surface and Coatings Technology*, vol. 261, pp. 278–288, 2015, doi: https://doi.org/10.1016/j.surfcoat.2014.11.017..

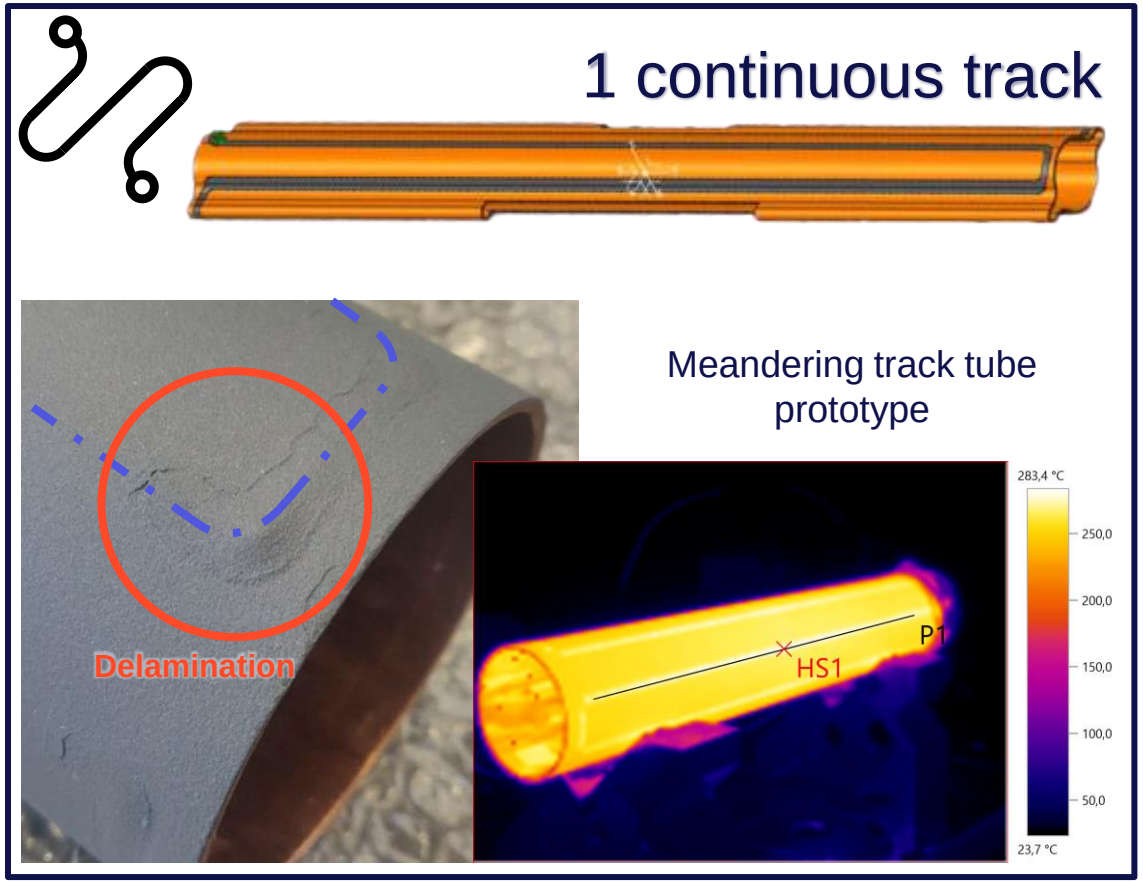
BOS – Materials Selection – Layer by Layer

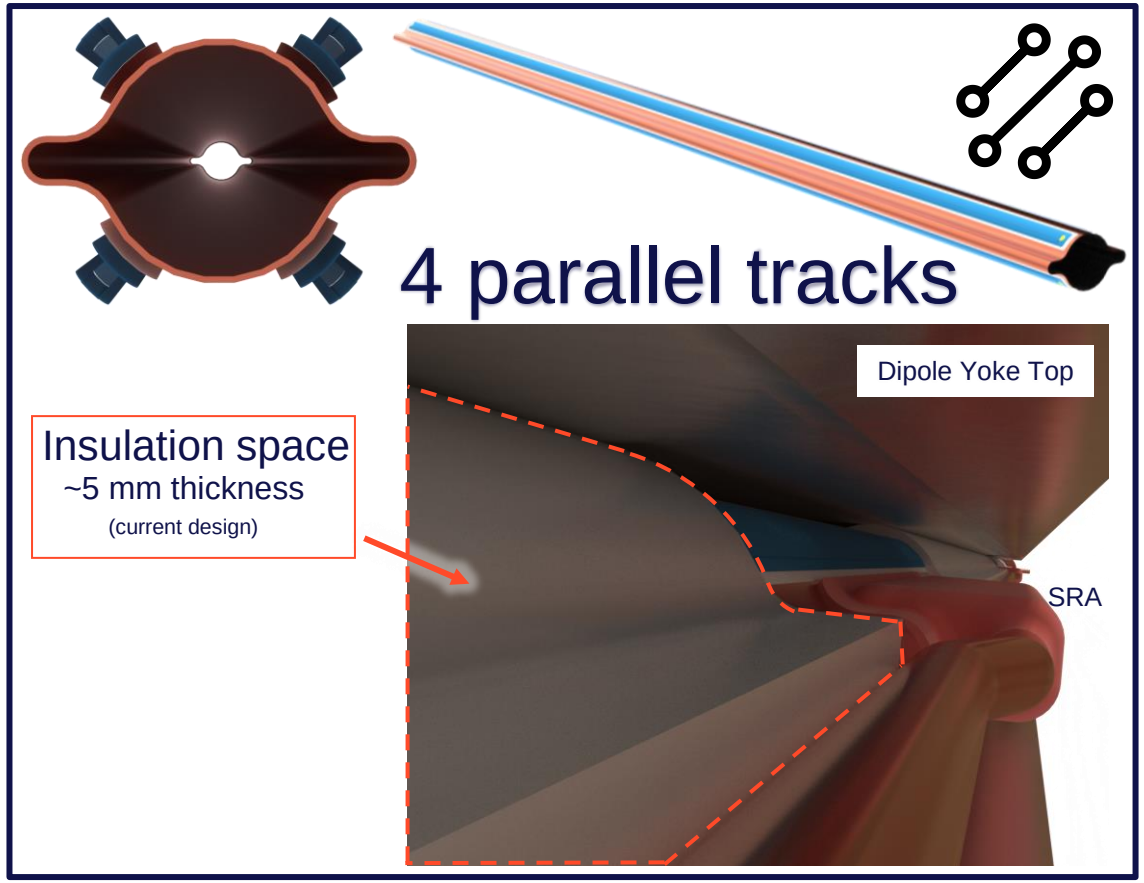
Layer	Function	Material		Process
Substrate		Cu-OFS		Extrusion
B	Mediation	NiCr20		APS
C1	Electrical Insulation	Alumina -Titania 87/13	Spinel 72/28	APS
T	Heating	Ti grade 4		Cold Spray
C2	Protection	Alumina -Titania 87/13	Spinel 72/28	APS

Cu-OFS = Oxygen Free, Silver added Copper (UNS C10700)
Alumina = Al_2O_3
Titania = TiO_2
Magnesia = MgO
Spinel = Alumina-Magnesia

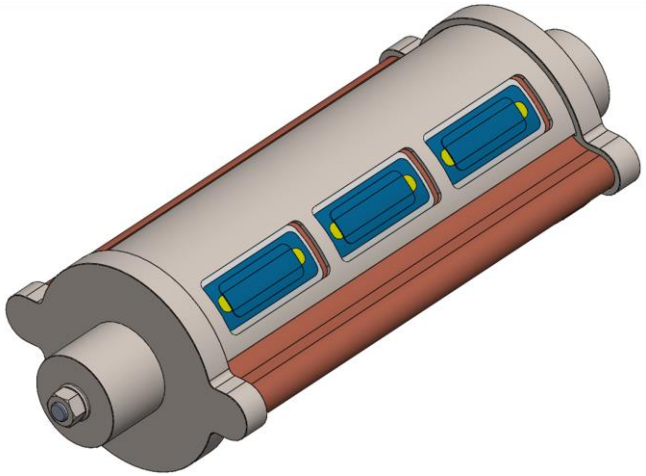


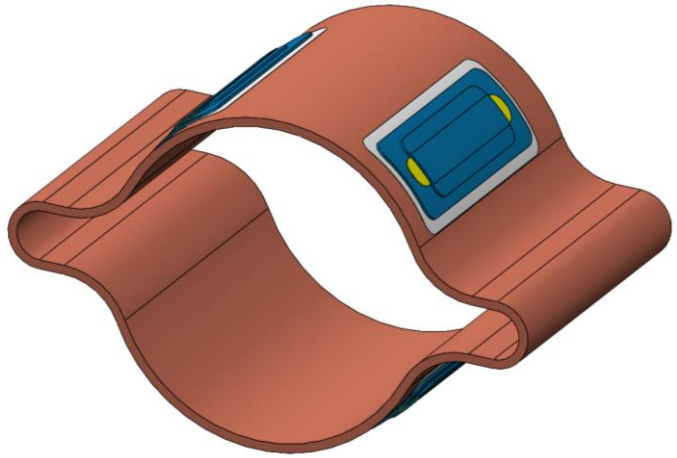
BOS – Meandering vs. Parallel Track Layout





BOS – Testing of Coatings





Spraying Setup → Individual mask for each coat → Therm. cycling sample after cutting

Layer	Thickness µm		Material	
B	100		NiCr20	
C1	300	500	Alumina-Titania	Spinel
T	200		Ti grade 4	
C2	500		Alumina-Titania	Spinel

(C2 always same material as C1)

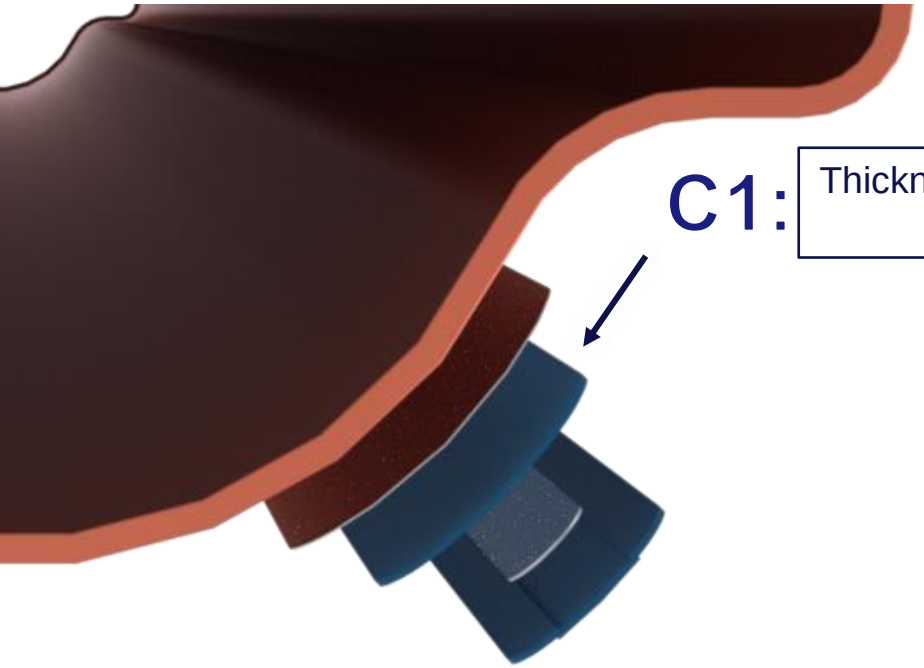
Alumina-Titania 500µm
Alumina-Titania 300µm

Spinel 500µm
Spinel 300µm

4 combinations

Thermal Cycling: 0 – 250°C
- In heat-treatment oven
- Max. 50 cycles
- Parameters tracked every 5 cycles

BOS – Scale-Up & Manufacturing Integration



C1: Thickness reduction: -100µm → Raw material savings: ~6-10 tons

e-beam welding test: SRA and VC

2m

12m dipole chamber

Synchrotron Radiation Absorber & Beam Positioning Monitor Sockets

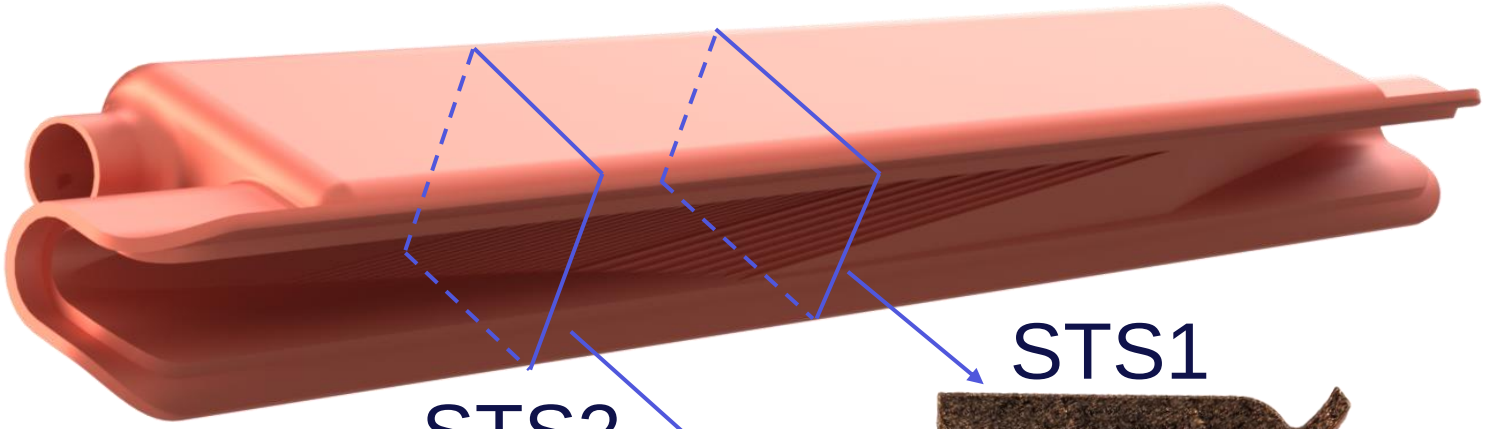
SRA – Synchrotron Radiation Absorber

Thermal Characterisation: RT-600°C

As-printed: CuCP, CuCrZr
Direct Age Hardened (DAH): CuCrZr

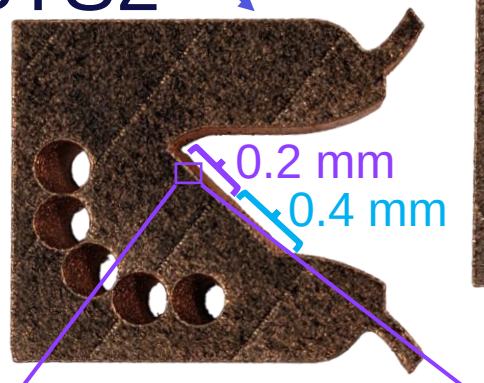
Thermal Expansion
Specific Heat Capacity
Thermal Conductivity
Density (RT only)

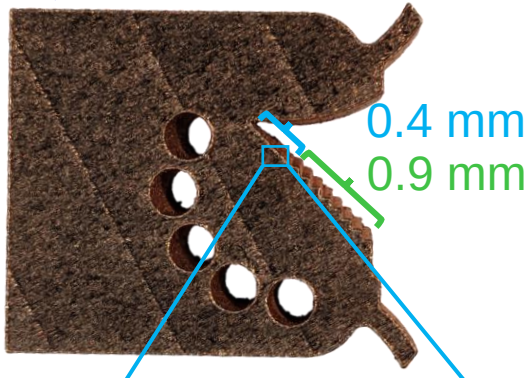
} Input for simulations

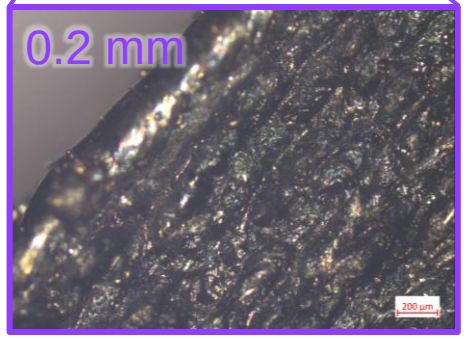


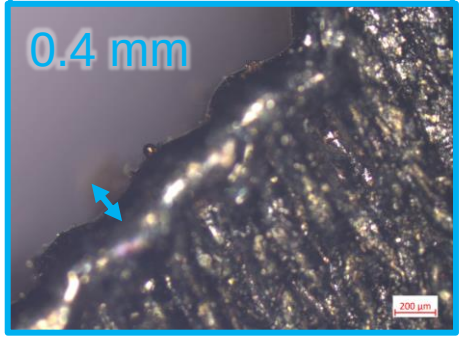
STS2

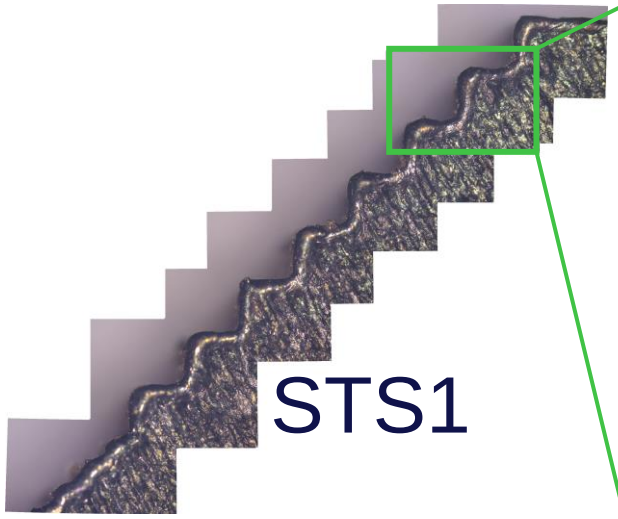
STS1

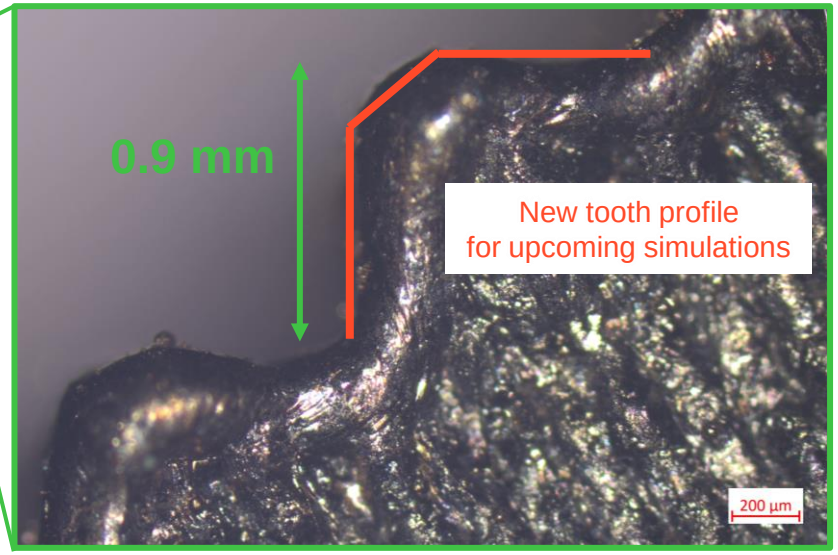








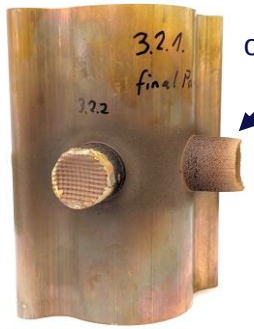




BPM – Beam Positioning Monitor Sockets

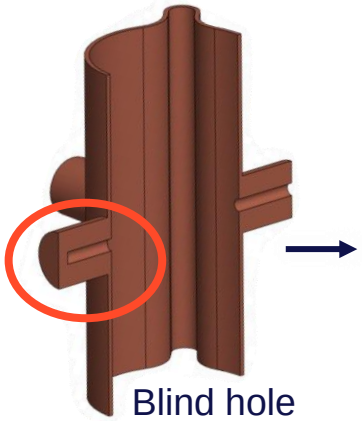
All around

No mask

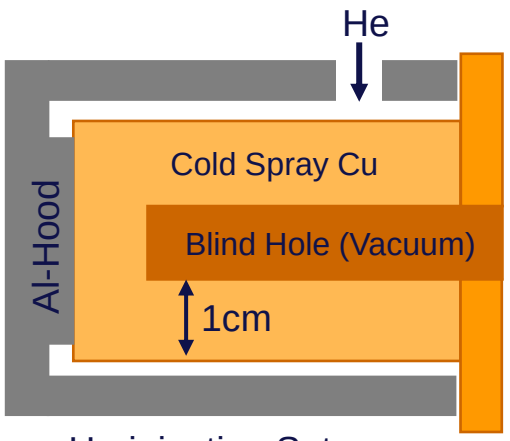


Mask

outer diameter: 26mm

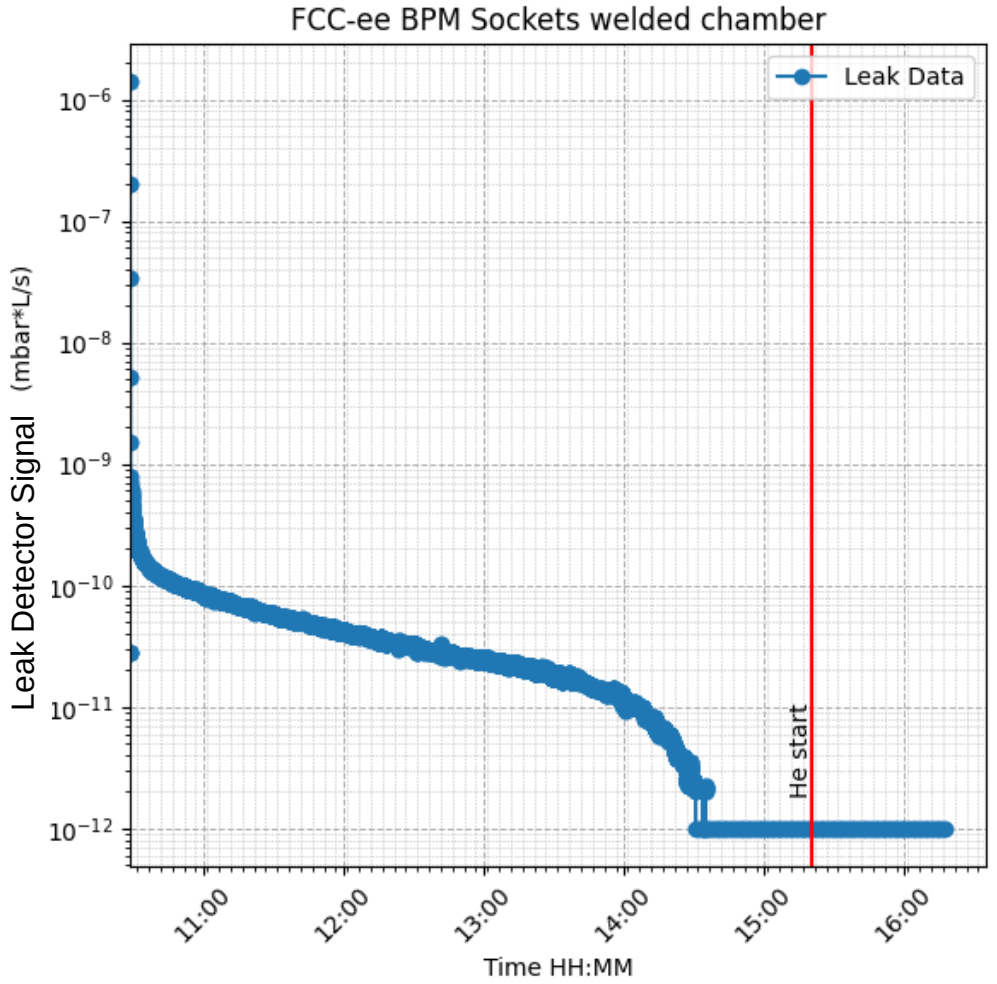


Blind hole diameter: 6mm



He-injection Setup

Photo of test setup



Thank you for your attention!

BOS-Outlook:

- Production of thermal cycling samples in progress
- Talks with companies for production of big prototypes

SRA-Outlook:

- Heat treatment optimisation study currently under way
- Fatigue and fracture testing campaign with partner institute

BPM Sockets-Outlook:

- Machining of samples for BPM test-fits
- Porosity analysis for spraying strategies
- Mechanical testing campaign including adhesion strength for Cold Spray Additively Manufactured Cu