FCC SRF cavities workpackages

(with an emphasis on coatings)

G. Rosaz, on behalf of the FCC SRF team

15.03.2021

Outline

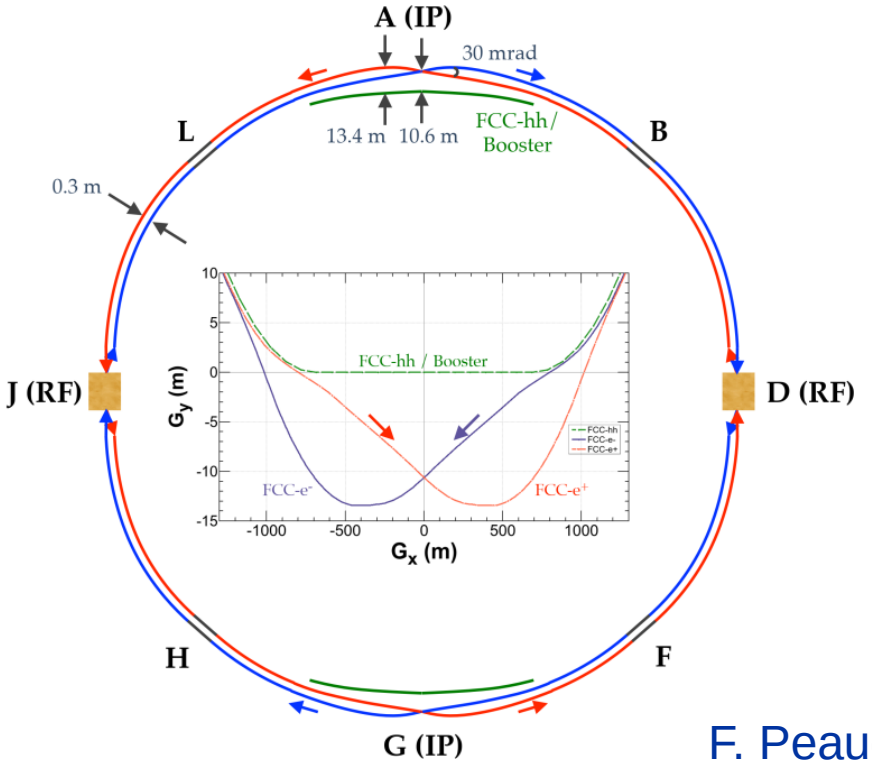
1. FCC RF systems
2. SRF Workpackages
3. Current status
4. 5 years plan

FCC RF Systems

FCC RF systems

FCC ee

- **Point J and D are straight sections dedicated to RF cavitie sand klystrons**
- **Involve 1364 cavities in total**
- **Straight section length: 2.2km (w/o kickers)**

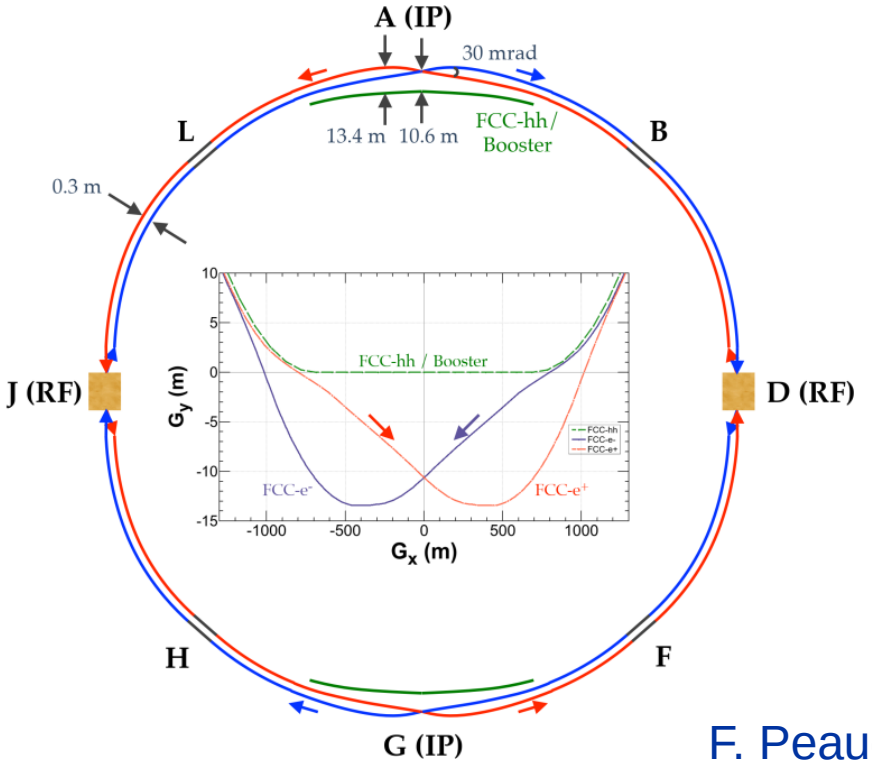


F. Peauger, Snowmass 2021

FCC RF systems

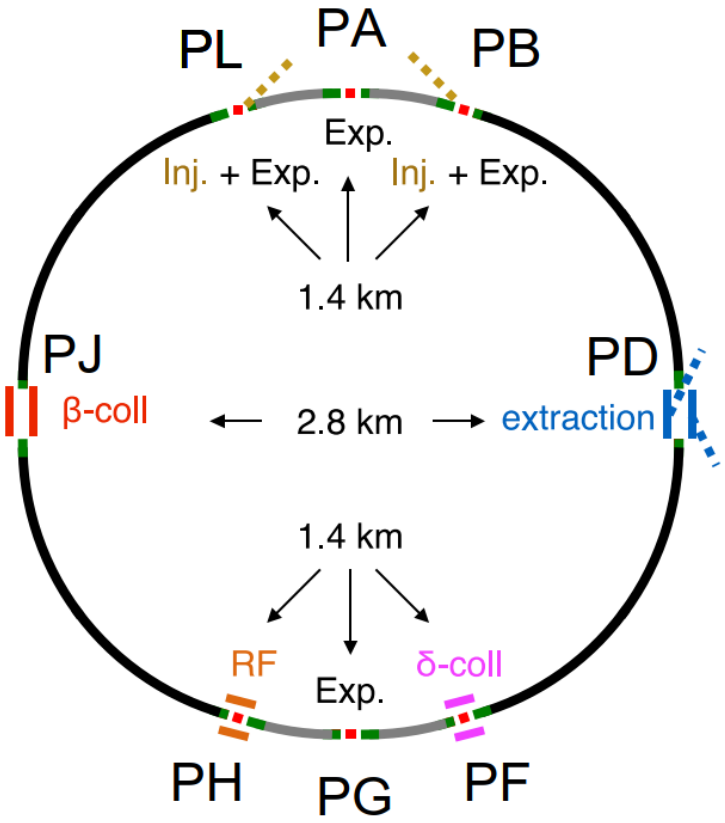
FCC ee

- Point J and D are straight sections dedicated to RF cavitie sand klystrons
- Involve 1364 cavities in total
- Straight section length: 2.2km (w/o kickers)



FCC hh

- RF system similar to LHC
- Total voltage of 48MV (24 LHC type cavities)

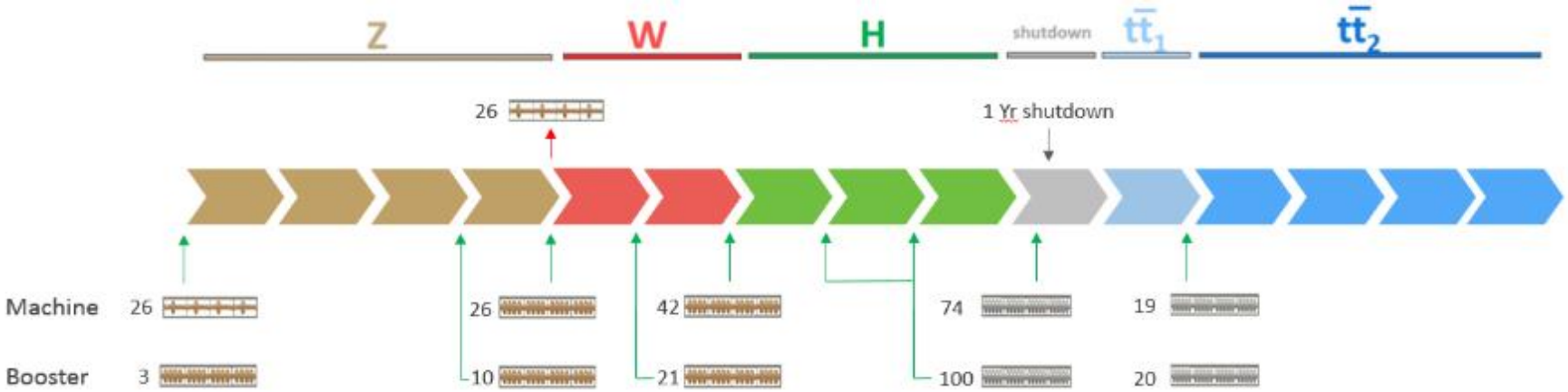


F. Peauger, Snowmass 2021

FCC ee RF system baseline

Fixed synchrotron radiation power: 50MW/beam
Elliptical shape cavities in CW mode

WP	V_{rf} [GV]	#bunches	I_{beam} [mA]
Z	0.1	16640	1390
W	0.44	2000	147
H	2.0	393	29
ttbar	10.9	48	5.4



F. Peauger, Snowmass 2021

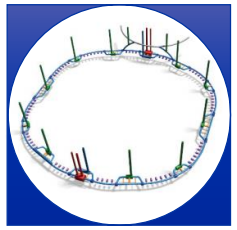
- 400 MHz 1-cell cavities
- Nb/Cu, 4.5 K
- 104 cavities
- Eacc=5 MV/m
- 1 MW /cav
- 4 cav./cryom.
- Re-used for FCC-hh

- 400 MHz 4-cell cavities
- Nb/Cu, 4.5 K
- 408 cavities
- Eacc=10 MV/m
- 1 MW to 200 kW per cav.
- 4 cav./cryom.

- 800 MHz 5-cell cavities
- bulk Nb, 2 K
- 852 cavities
- Eacc=20 MV/m
- 200 kW/cav.
- 4 cav./cryom.

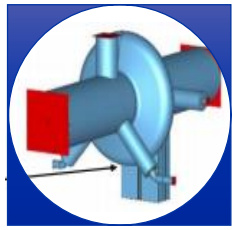
SRF Workpackages

FCC SRF R&D Workpackages



Coordination, parameters and design

- Coordination and review
- Challenge the operational scenarios (timeline, cost,..)

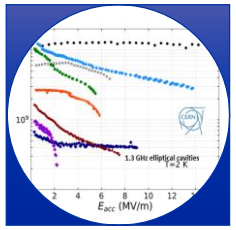


Cavity Studies & Beam Dynamics

- Determine the cavity design for each FCC machines.
- Validate the HOM damping schemes
- Carry out the beam-cavity interactions studies
- Evaluate the cavity control system (LLRF) challenges

Cavity Engineering & Fabrication

- Push the limits of fabrication technologies: seamless, internal welding, precision machining, 3D printing
- Built a cavity for Z machine



SRF & Substrate Preparation

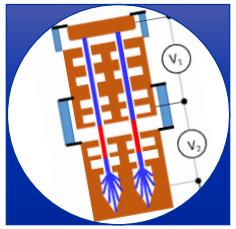
- Establish the limits of surface preparation and Nb coatings
- Optimize HIPIMS coatings using 1.3 GHz seamless cavities
- Pursue exploration of A15
- Prepare and validate a cavity for Z machine

Cryomodule Development

- Develop a test bed for new cavity, FPC and CM technologies
- re-assess generic CM challenges: thermal performances, magnetic shielding, cavity & FPC support,…
- study HOM power extraction schemes for Z machine
- define feasibility of 2K and 4.5 K operation built a CM mockup to validate cavity for Z machine

FPC & HOM Couplers

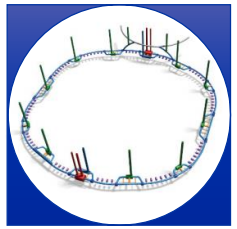
- Push the limits of FPC performances
- Towards 1 MW (baseline)
- Towards large adaptability HOMC mechanical design & production



High power RF Systems

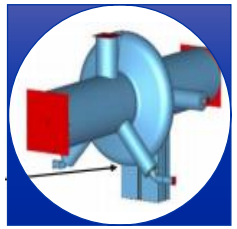
- Challenge RF power systems and power distribution schemes
- Demonstrate HE two stage technology (baseline)
- Evaluate alternative technologies

FCC SRF R&D Workpackages



Coordination, parameters and design

- Coordination and review
- Challenge the operational scenarios (timeline, cost,..)

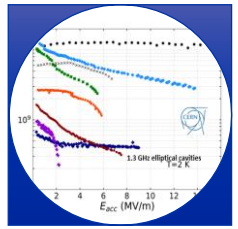


Cavity Studies & Beam Dynamics

- Determine the cavity design for each FCC machines.
- Validate the HOM damping schemes
- Carry out the beam-cavity interactions studies
- Evaluate the cavity control system (LLRF) challenges

Cavity Engineering & Fabrication

- Push the limits of fabrication technologies: seamless, internal welding, precision machining, 3D printing
- Built a cavity for Z machine



SRF & Substrate Preparation

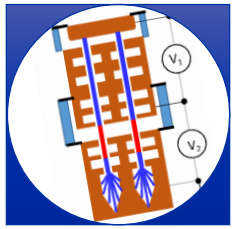
- Establish the limits of surface preparation and Nb coatings
- Optimize HIPIMS coatings using 1.3 GHz seamless cavities
- Pursue exploration of A15
- Prepare and validate a cavity for Z machine

Cryomodule Development

- Develop a test bed for new cavity, FPC and CM technologies
- re-assess generic CM challenges: thermal performances, magnetic shielding, cavity & FPC support,…
- study HOM power extraction schemes for Z machine
- define feasibility of 2K and 4.5 K operation built a CM mockup to validate cavity for Z machine

FPC & HOM Couplers

- Push the limits of FPC performances
- Towards 1 MW (baseline)
- Towards large adaptability HOMC mechanical design & production



High power RF Systems

- Challenge RF power systems and power distribution schemes
- Demonstrate HE two stage technology (baseline)
- Evaluate alternative technologies

Workpackages objectives

Workpackages objectives

WP2: Cavity engineering and fabrication

- **Investigate alternative manufacturing techniques (hydroforming, electrohydroforming, electroforming…)**
- **Welding process optimization (internal e-beam welding)**
- **Provide 1.3GHz substrates for WP3**
- **Build a cavity for a mock-up cryomodule**

Workpackages objectives

WP2: Cavity engineering and fabrication

- Investigate alternative manufacturing techniques (hydroforming, electrohydroforming, electroforming…)
- Welding process optimization (internal e-beam welding)
- Provide 1.3GHz substrates for WP3
- Build a cavity for a mock-up cryomodule

WP3: SRF and substrate preparation

- Optimize substrate preparation prior to coating (electropolishing)
- Optimize HiPIMS coatings on 1.3GHz in view of transfer to 400MHz objects
- Continue the development and RF characterization of A15/Cu layers
- Deliver a cavity for a mock-up cryomodule

Workpackages objectives

WP2: Cavity engineering and fabrication

- Investigate alternative manufacturing techniques (hydroforming, electrohydroforming, electroforming…)
- Welding process optimization (internal e-beam welding)
- Provide 1.3GHz substrates for WP3
- Build a cavity for a mock-up cryomodule

WP3: SRF and substrate preparation

- Optimize substrate preparation prior to coating (electropolishing)
- Optimize HiPIMS coatings on 1.3GHz in view of transfer to 400MHz objects
- Continue the development and RF characterization of A15/Cu layers
- Deliver a cavity for a mock-up cryomodule

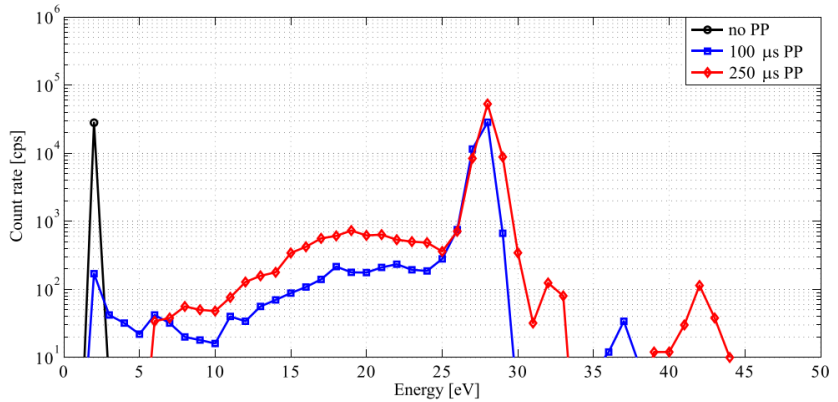
Detailed tasks lists to be established by April 2021

Current status

(of thin films...)

Bipolar HiPIMS

- **HiPIMS+PP characterization**
- **Extensive plasma characterization carried out** [1]
- **Thin film characterization**
  - Structure [2]
  - DC SC properties
  - RF SC properties
- **Plasma and coatings simulation (cf. F. Manke / G. Rosaz talks)**



Time-integrated EDFs of Nb^+ for the case without PP, +50 V PP of 100 μs, and 250 μs duration.

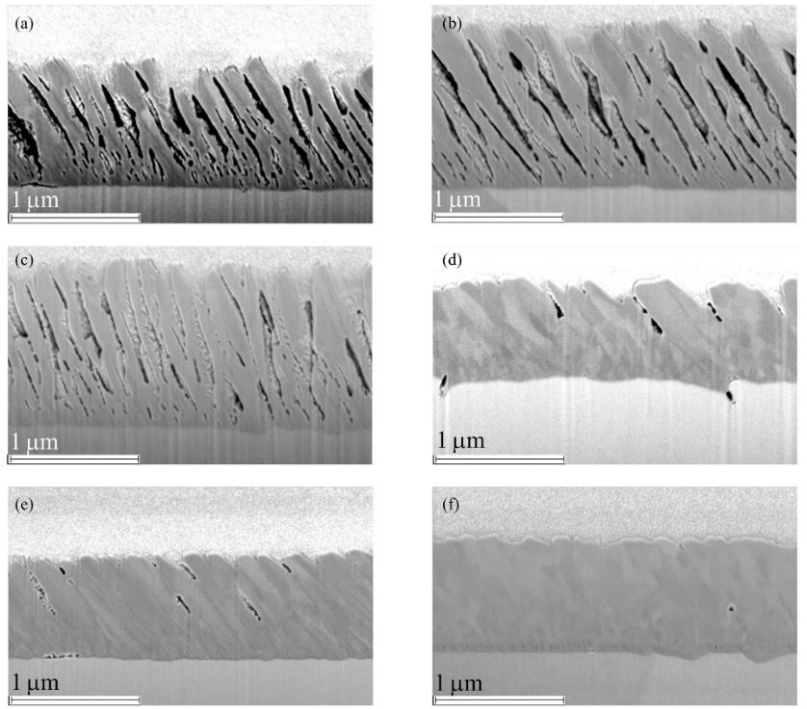


Fig. 5. Nb films FIB cross sections of samples at 90° coated in: (a) DCMS with grounded substrate, (b) DCMS with −50 V biased substrate, (c) HiPIMS with grounded substrate, (d) HiPIMS with −50 V biased substrate, (e) HiPIMS with grounded substrate and +50 V PP, (f) HiPIMS with grounded substrate and +100 V PP.

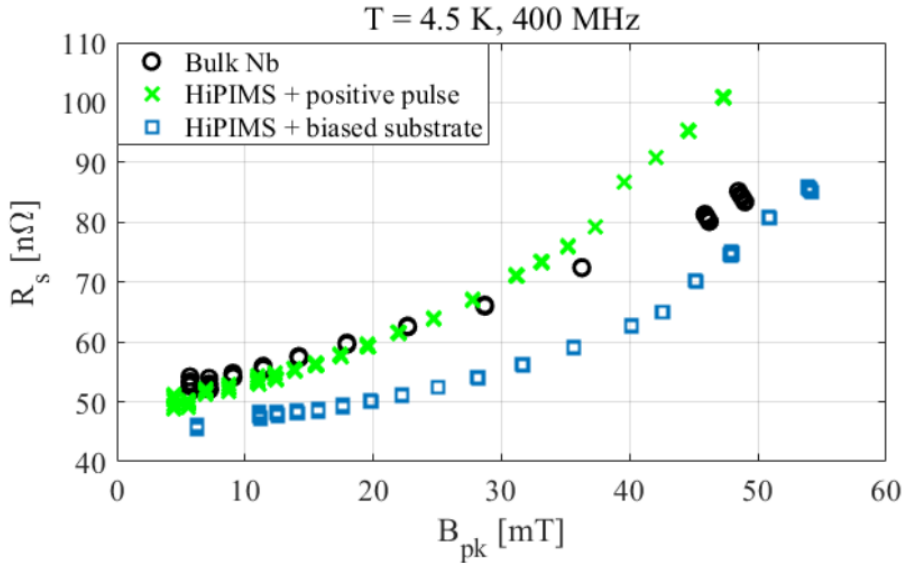
[1] F. Avino et al, Evidence of ion energy distribution shift in HiPIMS plasmas with positive pulse, Plasma Sources Sci. Technol. 28 (2019) 079501 (2pp), https://doi.org/10.1088/1361-6595/ab2b1d

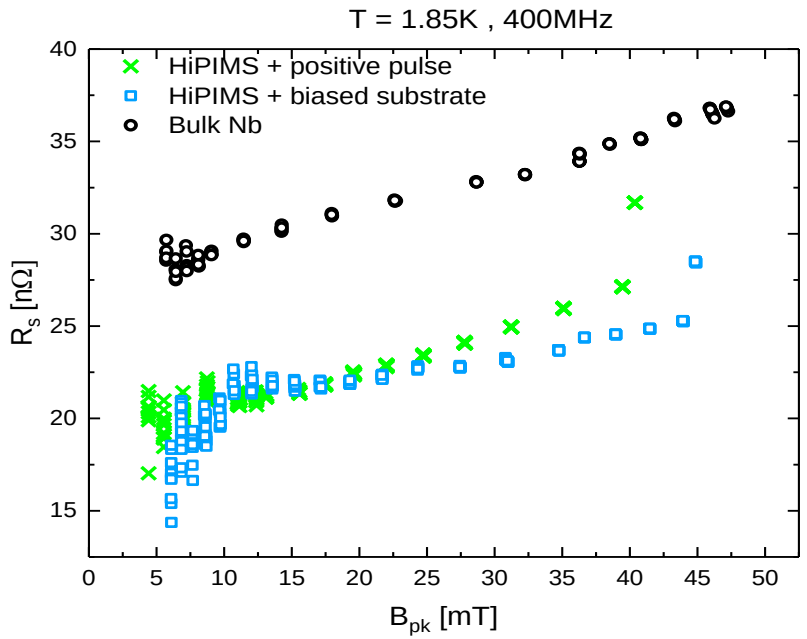
[2] F. Avino et al, Improved film density for coatings at grazing angle of incidence in high power impulse magnetron sputtering with positive pulse, Thin Solid Films 706 (2020) 138058, https://doi.org/10.1016/j.tsf.2020.138058

HiPIMS RF Performance

- **HiPIMS coatings (on QPR)**
- **Biased HiPIMS and HiPIMS+PP**
- **Great performance wrt bulk Nb**
- **Reaching QPR sensitivity limit**
- **Transfer to 1.3GHz cavities**
- **Pursue fundamental investigations**

(cf: ***Chung-Yang Wang*** *talk)*





F. Avino et al, TTC Meeting 2020

1.3GHz Cavities

2 Reference substrates currently used (cf L. Vega-Cid / L. Lain-Amador)

- Bulk Cu (WP2)
- Electroformed cavity

HiPIMS leads to optimal R_{BCS}

1.10^{10} Q_0 at low field reachable

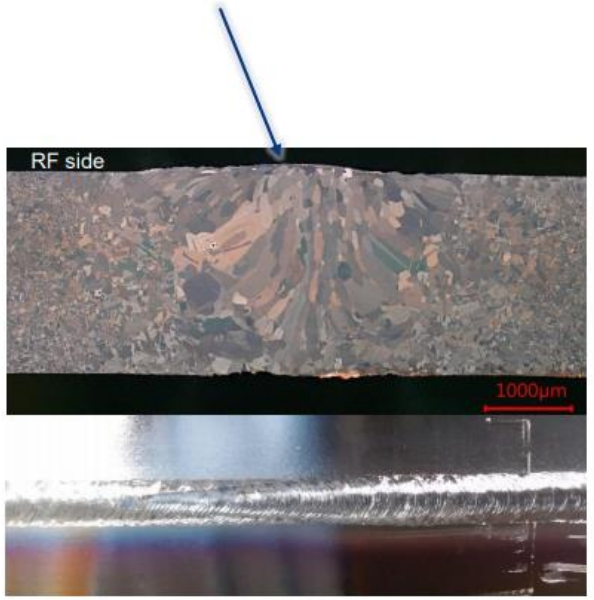
Manufacturing optimization on-going

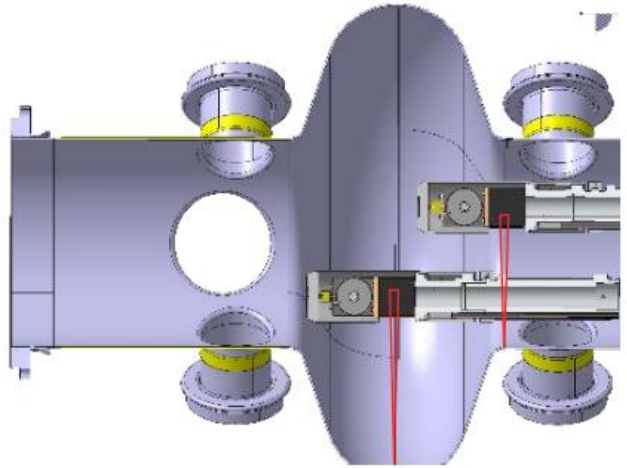
- Internal e-beam welding
- Tests on 1.3GHz for 400MHz scale-up

Application to 400 MHz cavity

→ Welding iris and equator from inside

→ Possibility to increase the thickness (from 2.3 to 2.6mm ?) to allow more margin for internal surface polishing if required

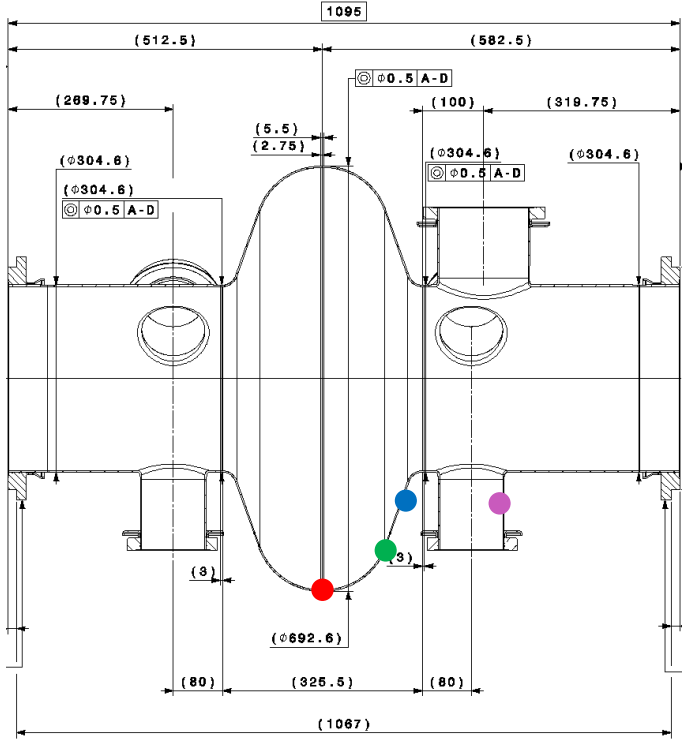


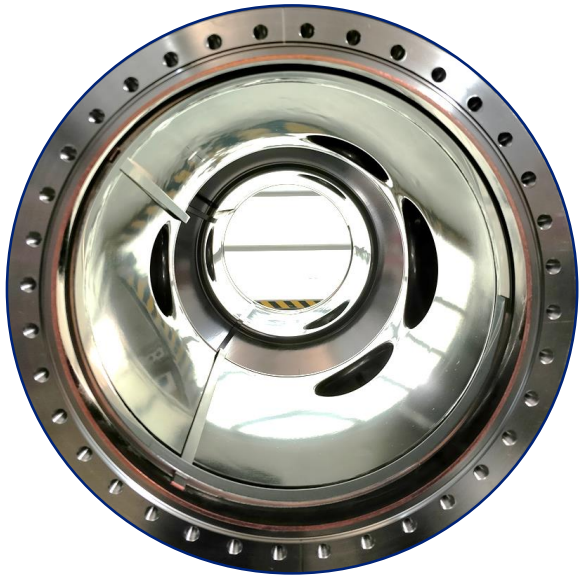


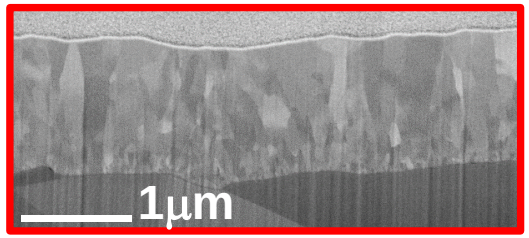
T. Demazière, G. Favre (CERN)

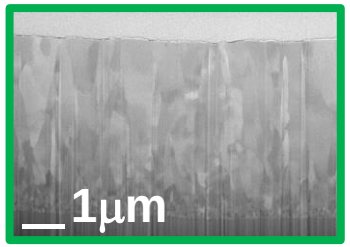
HiPIMS Scale-up

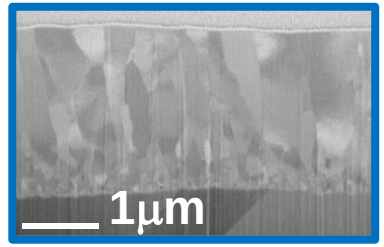
- First trials on 400MHz LHC cavity
- HiPIMS + PP (no cathode change needed)
- Layer densification confirmed
- Coating rates calibrated
- 2022: plan first RF testing

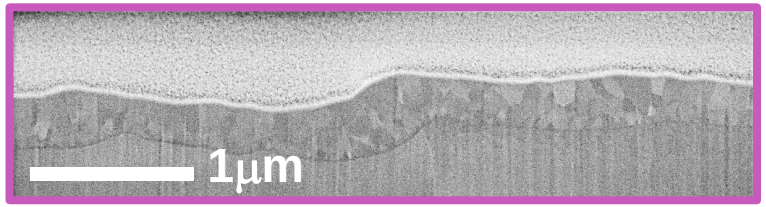






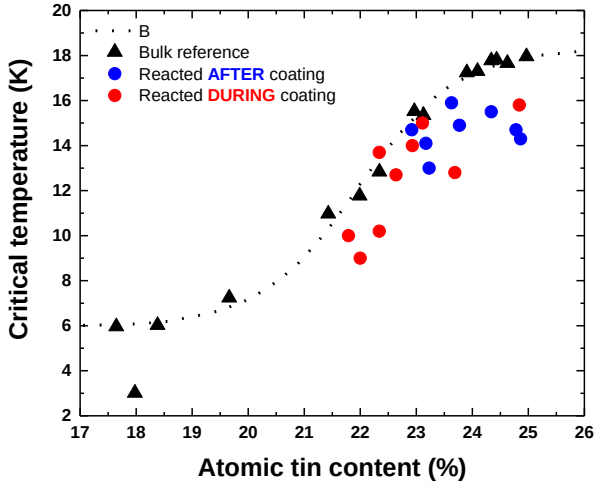


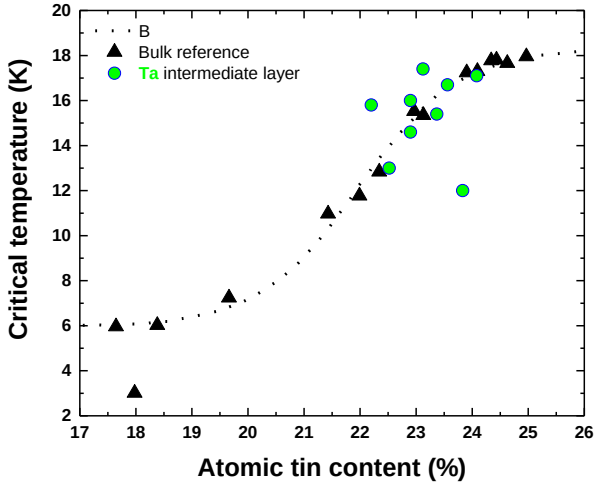


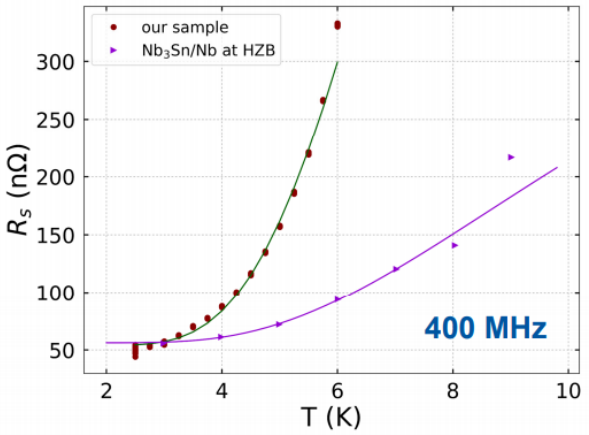


A15 / Cu

Nb_3Sn





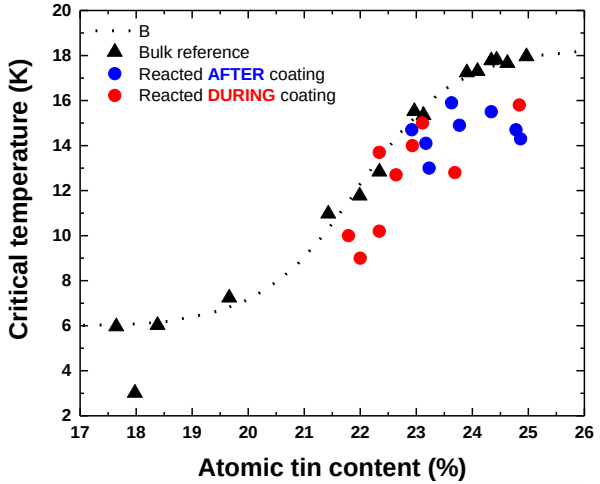


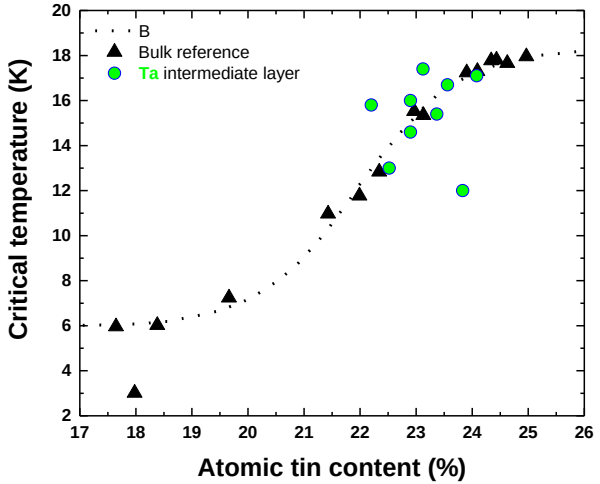
- Cf M. Arzeo talk (SRF2019)
- Optimization of RF performance on-going

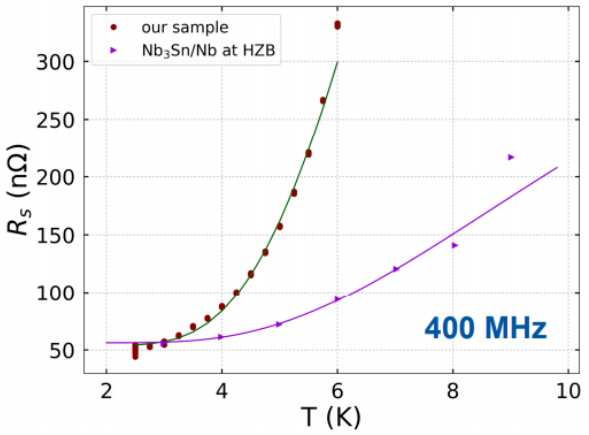
K. Ilyina-Brunner et al, Development of sputtered Nb3Sn films on copper substrates for superconducting radio-frequency applications *Supercond. Sci. Technol.* 32 (2019) 035002 http://dx.doi.org/10.1088/1361-6668/aaf61f

A15 / Cu

Nb_3Sn



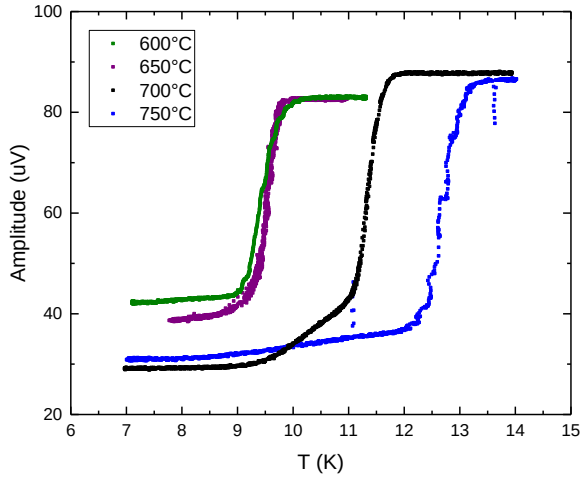




- Cf M. Arzeo talk (SRF2019)
- Optimization of RF performance on-going

K. Ilyina-Brunner et al, Development of sputtered Nb3Sn films on copper substrates for superconducting radio-frequency applications *Supercond. Sci. Technol.* 32 (2019) 035002 http://dx.doi.org/10.1088/1361-6668/aaf61f

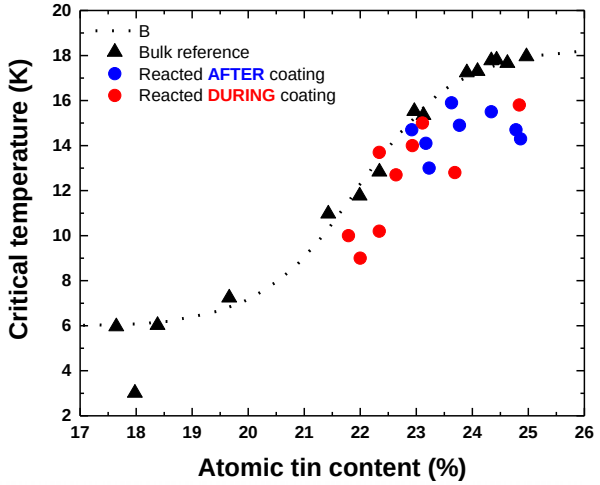
V_3Si

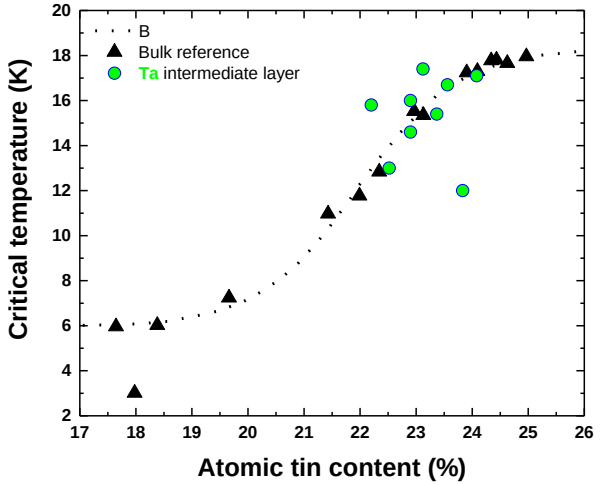


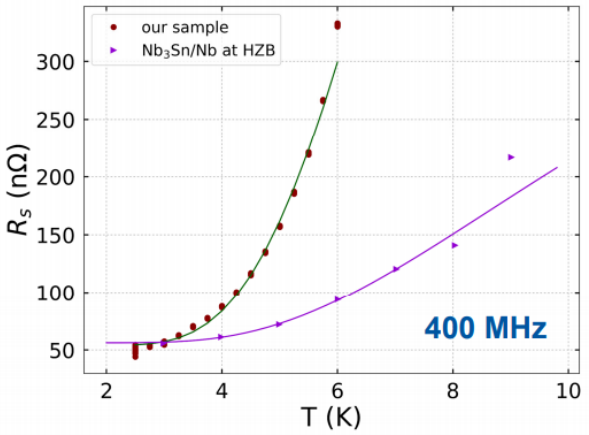
- Cf S. Fernandez talk (TTC 2021)
- Tc to be optimized

A15 / Cu

Nb_3Sn



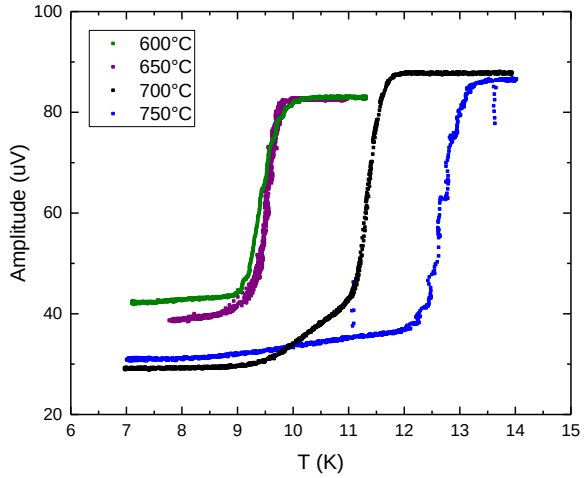




- Cf M. Arzeo talk (SRF2019)
- Optimization of RF performance on-going

K. Ilyina-Brunner et al, Development of sputtered Nb3Sn films on copper substrates for superconducting radio-frequency applications *Supercond. Sci. Technol.* 32 (2019) 035002 http://dx.doi.org/10.1088/1361-6668/aaf61f

V_3Si

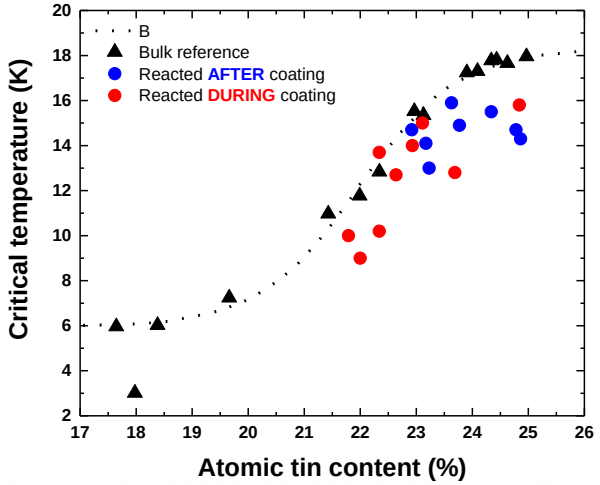


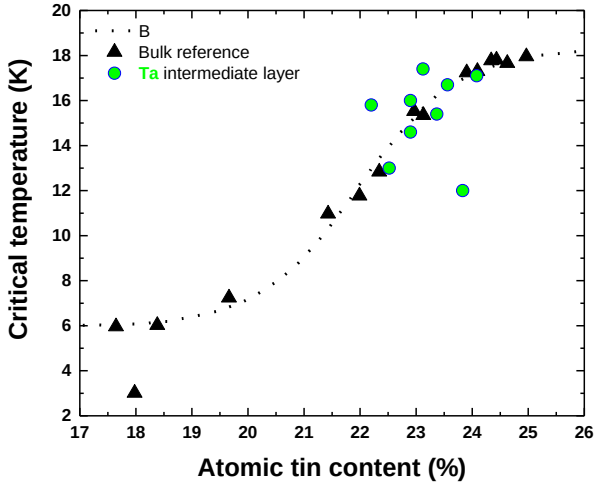
- Cf S. Fernandez talk (TTC 2021)
- Tc to be optimized

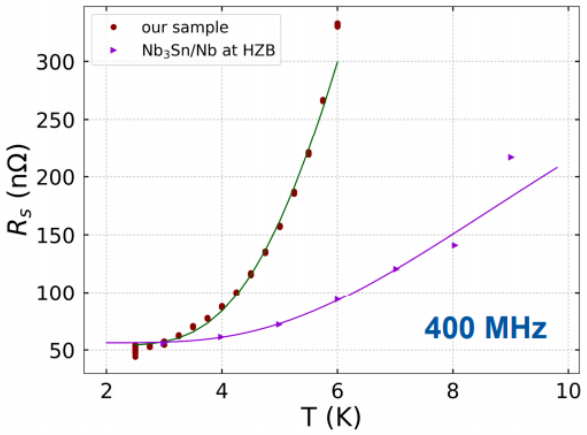
HiPIMS under investigation for those materials

A15 / Cu

Nb_3Sn



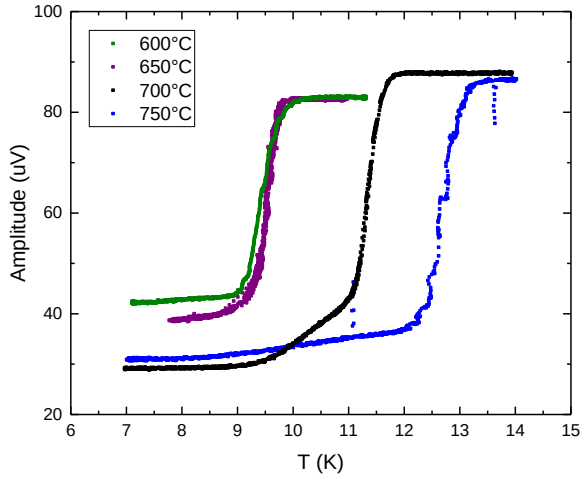




- Cf M. Arzeo talk (SRF2019)
- Optimization of RF performance on-going

K. Ilyina-Brunner et al, Development of sputtered Nb3Sn films on copper substrates for superconducting radio-frequency applications *Supercond. Sci. Technol.* 32 (2019) 035002 http://dx.doi.org/10.1088/1361-6668/aaf61f

V_3Si

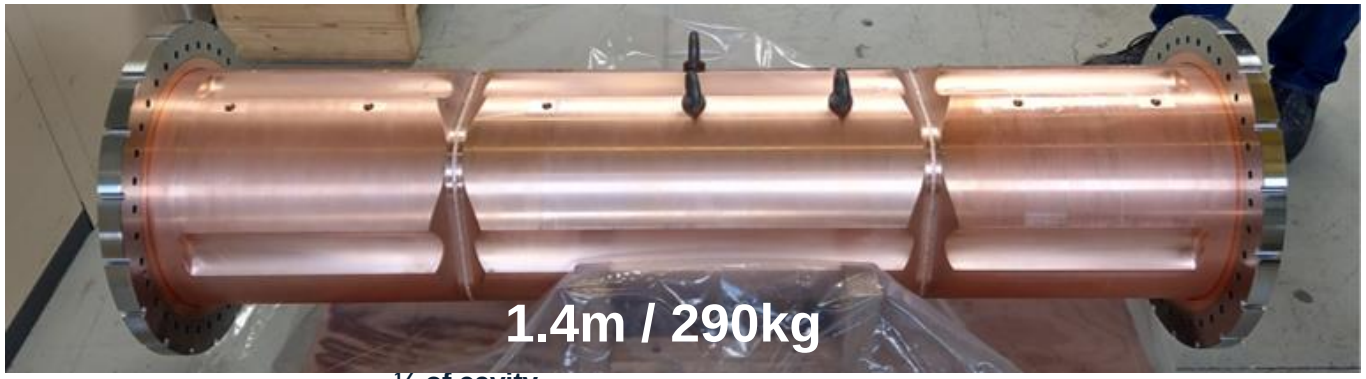


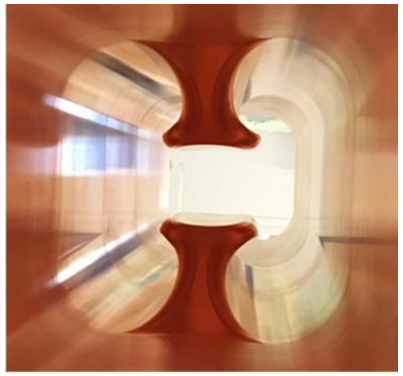
- Cf S. Fernandez talk (TTC 2021)
- Tc to be optimized

HiPIMS under investigation for those materials

SCALE UP WILL BE CHALLENGING

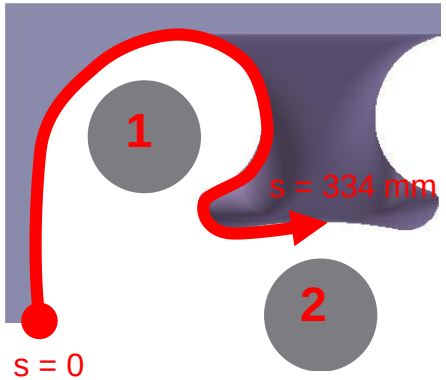
WOWCC

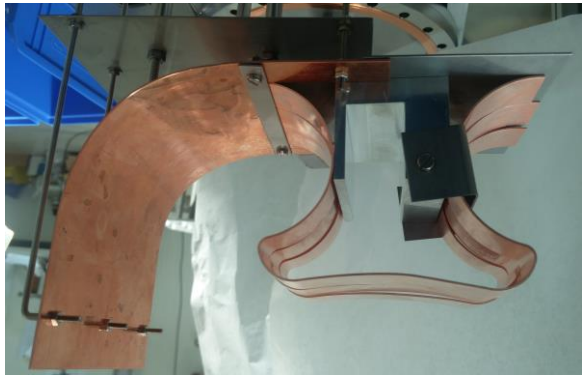


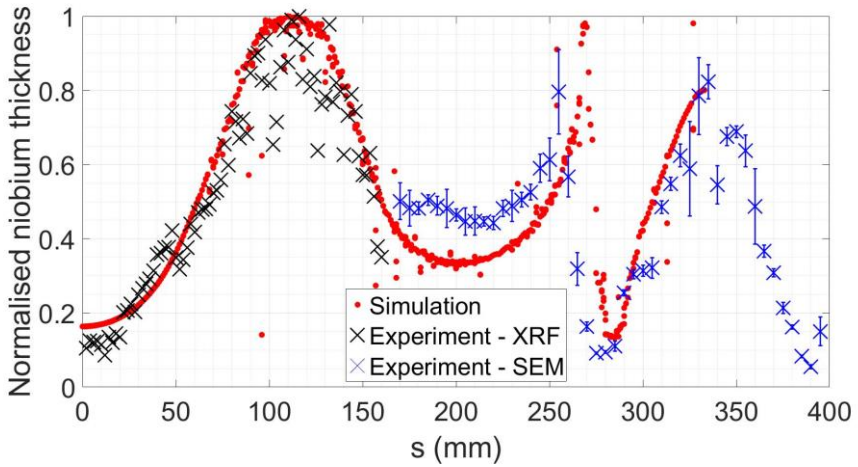


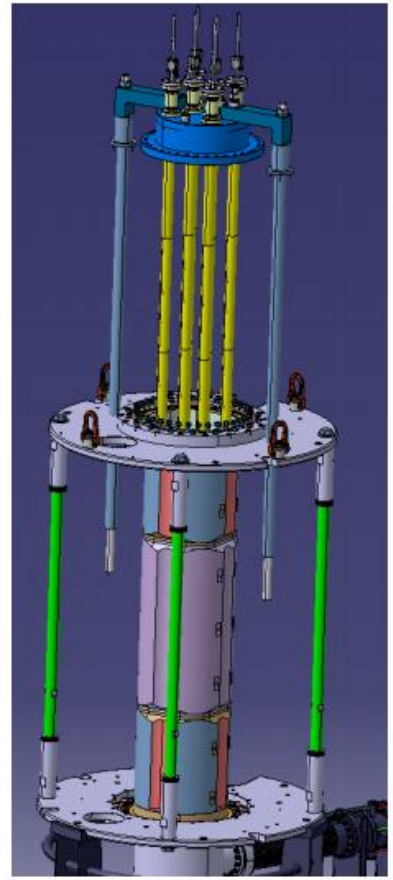
~ ¼ of cavity

- FCC hh
- Cu crab cavities
- Coating setup development
- Trials on mock-up
- Coating profile assessement
- First coating on cavity: fall 2021









F. Avino et al, Development of coating system for the Wide Open Waveguide crab cavity,TTC 2020

5 years major milestones

2021: Optimization of coatings on seamless cavities / WOWCC coating trial

2022: First RF test on HiPIMS coated 400MHz cavity

2023: Evaluation of A15/Cu potential

2024: First FCC Prototype

2025: Cavity delivery for CM assembly

Summary / Perspectives

Optimization of Nb/Cu technology

1. Substrate manufacturing
2. Coating recipe

Improve diagnostics (thermal mapping)

400MHz scale-up

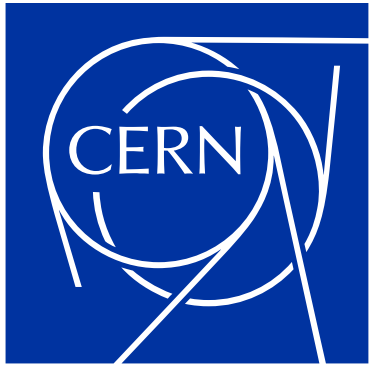
WOWCC

CM demonstrator

Alternative materials

Finalize collaboration agreements

Thank you for your attention



home.cern