

# 400 MHZ CAVITY PROGRAM AT CERN

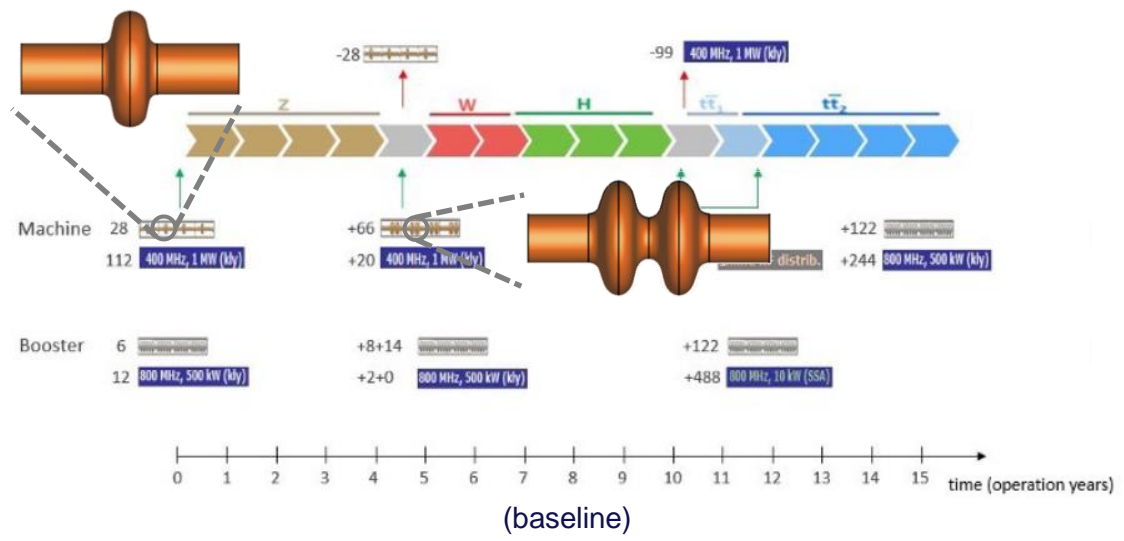
(coating & surface preparation)

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# Motivation

F. Gerigk, *Key RF R&D for future projects*, Chamonix Workshop 2024

Nb-coated Cu cavities are being considered for the Z, W and H machines variants

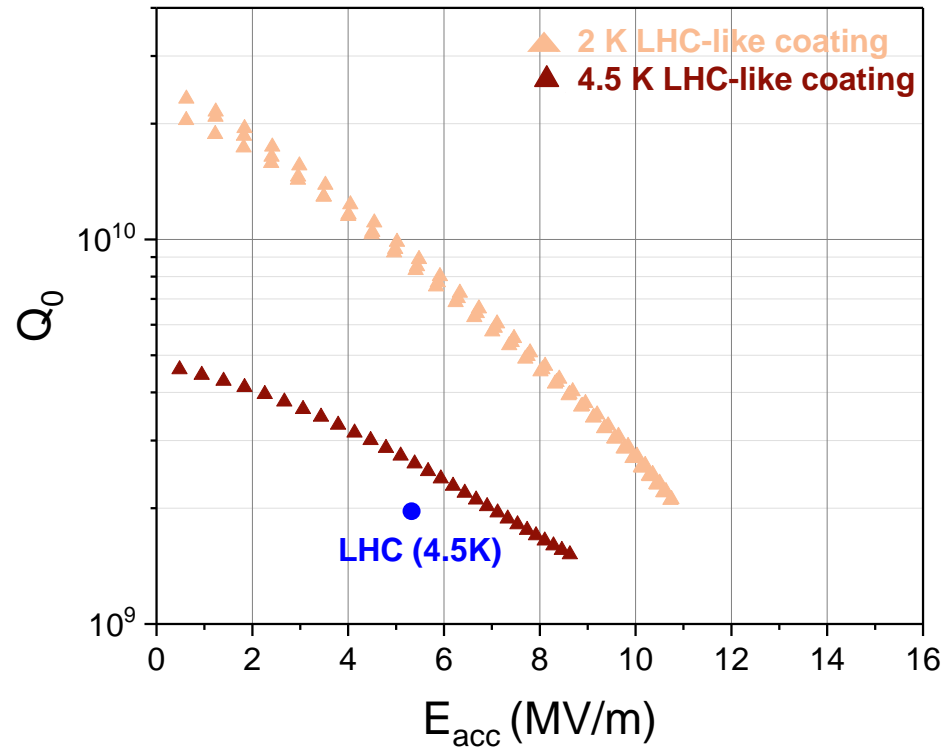


Option of using 2-cell 400 MHz cavities for the Z is also under study

**Either 1-cell + 2-cell or just 2-cell 400 MHz Nb/Cu cavities**

# Nb/Cu cavities

Reduce Load on Cryogenics



# Nb/Cu cavities

Reduce Load on Cryogenics

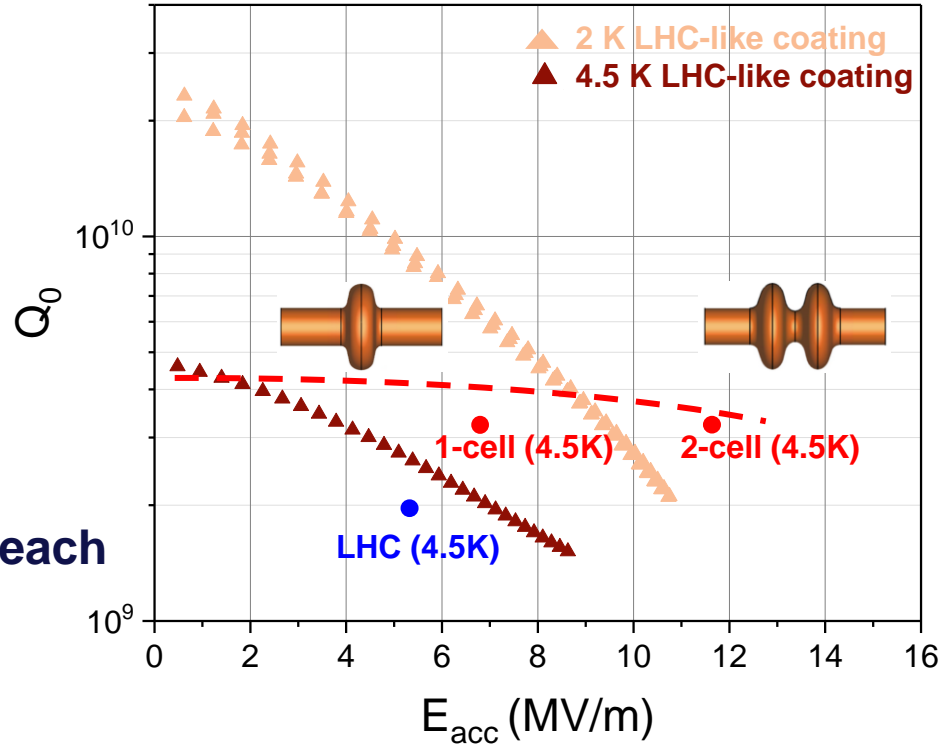
Specifications target FCC-ee:

1-cell:  $3.3 \times 10^9$  @ 6.9 MV/m

2- cells:  $3.3 \times 10^9$  @ 13.2 MV/m



Cure Q-slope & extend field reach



# Nb/Cu cavities

- Nb coating is currently performed with High Power Impulse Magnetron Sputtering (HiPIMS)



400 MHz cavity before & after coating

- Prior to coating, Cu:
  - Electropolishing (smooth surface)
  - Passivation (prevents Cu oxidation, improves film adhesion)
- R&D on samples and 1.3 GHz test cavities first, know-how is then transferred to 400 MHz

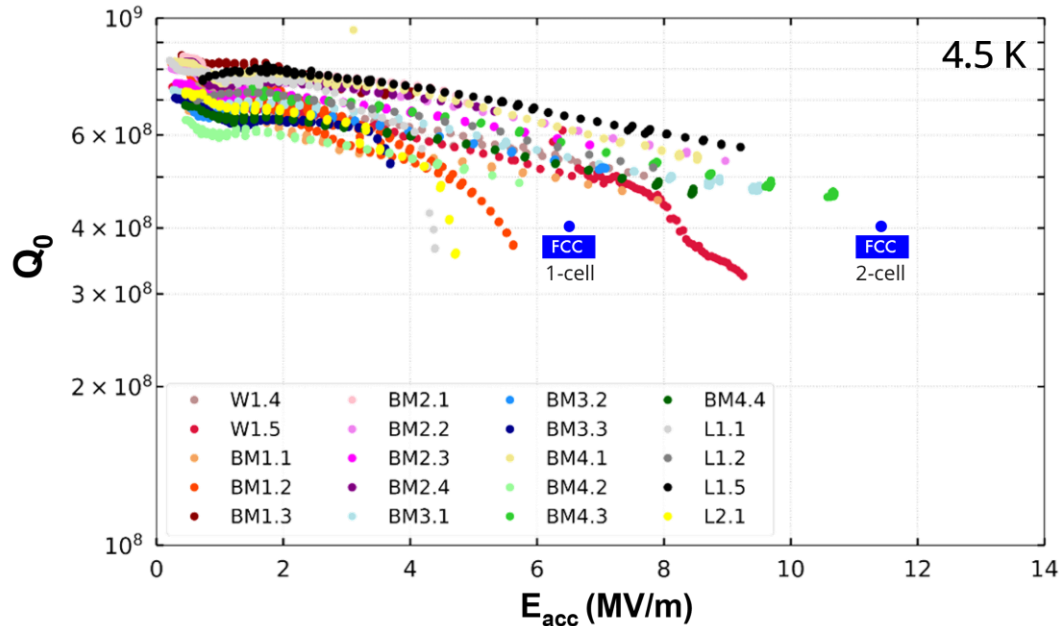


# STATUS & GOALS

1.3 GHz and 400 MHz cavities

# 1.3 GHz test cavities: results

(FCC-ee performance targets scaled for 1.3 GHz substrates)

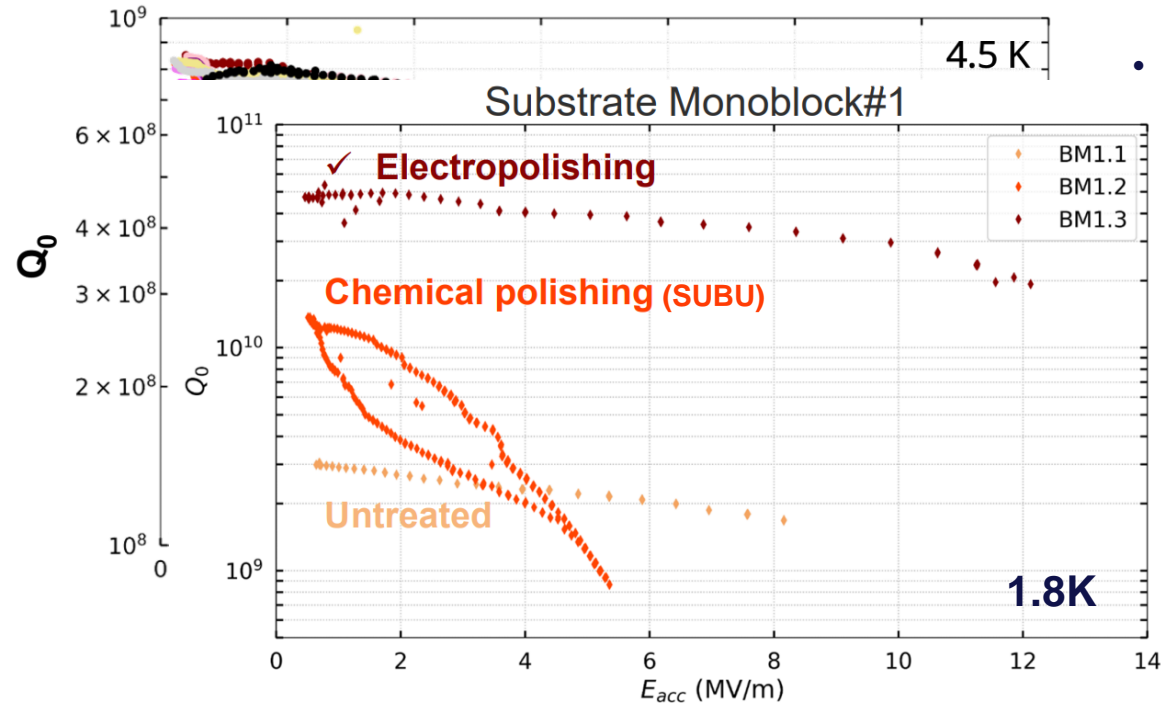


- High repeatability at 4.5K
- 1-cell target reached consistently
- 2-cells target within reach

How?

# 1.3 GHz test cavities: results

(FCC-ee performance targets scaled for 1.3 GHz substrates)

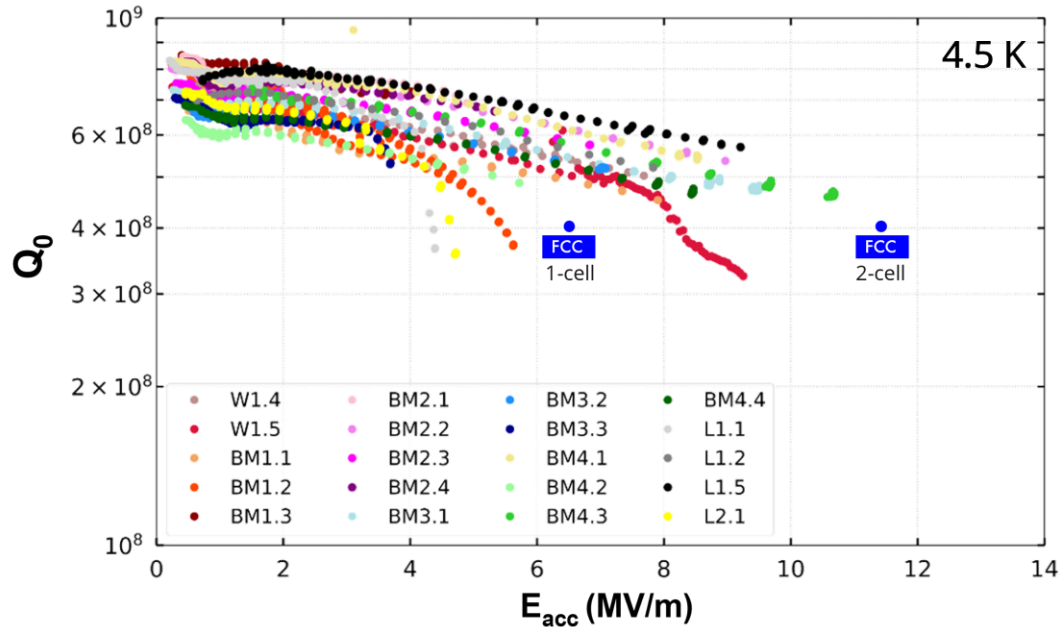


- Improved Cu surface treatment  
Electropolishing (EP), instead of SUBU as in LHC  
Passivation to avoid layer delamination.



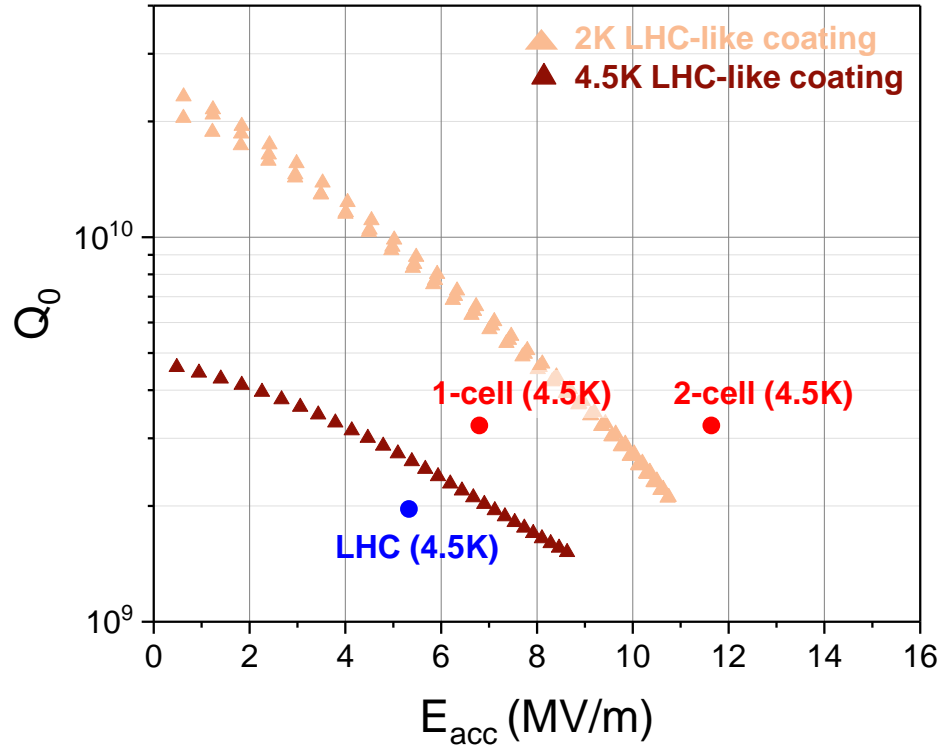
# 1.3 GHz test cavities: results

(FCC-ee performance targets scaled for 1.3 GHz substrates)

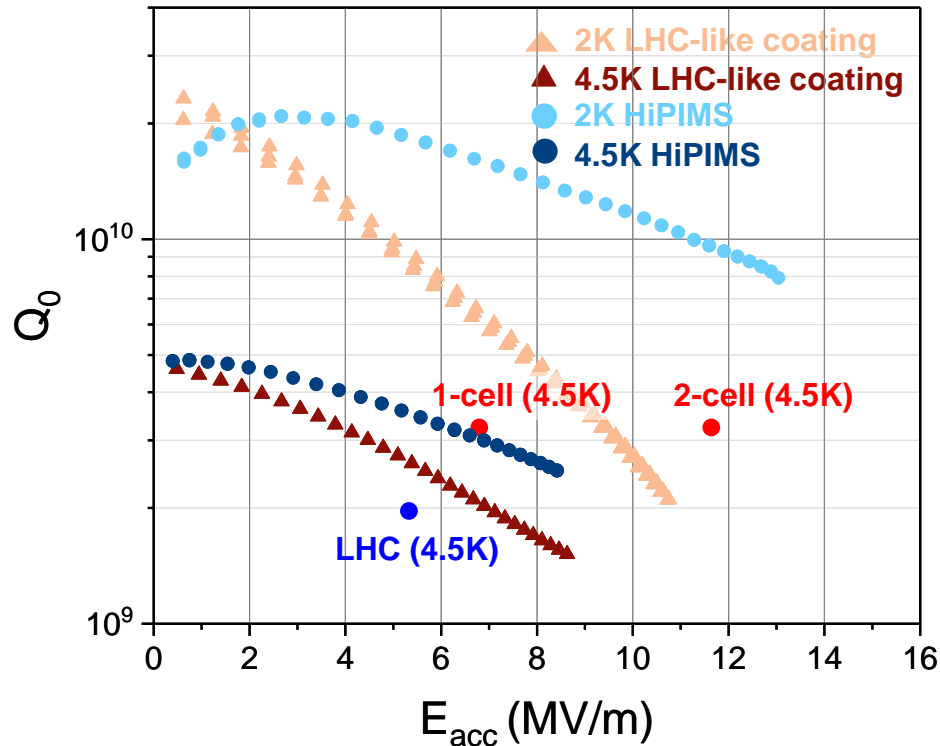


- **Improved Cu surface treatment**
- **Seamless substrates**  
(no welds at equator)  
Bulk machined (BM) & electroformed (L), gave the best results.
- **Optimized coating recipe**  
HiPIMS + DC substrate bias  
(6  $\mu\text{m}$  and -75 V)

# 400 MHz HiPIMS: results

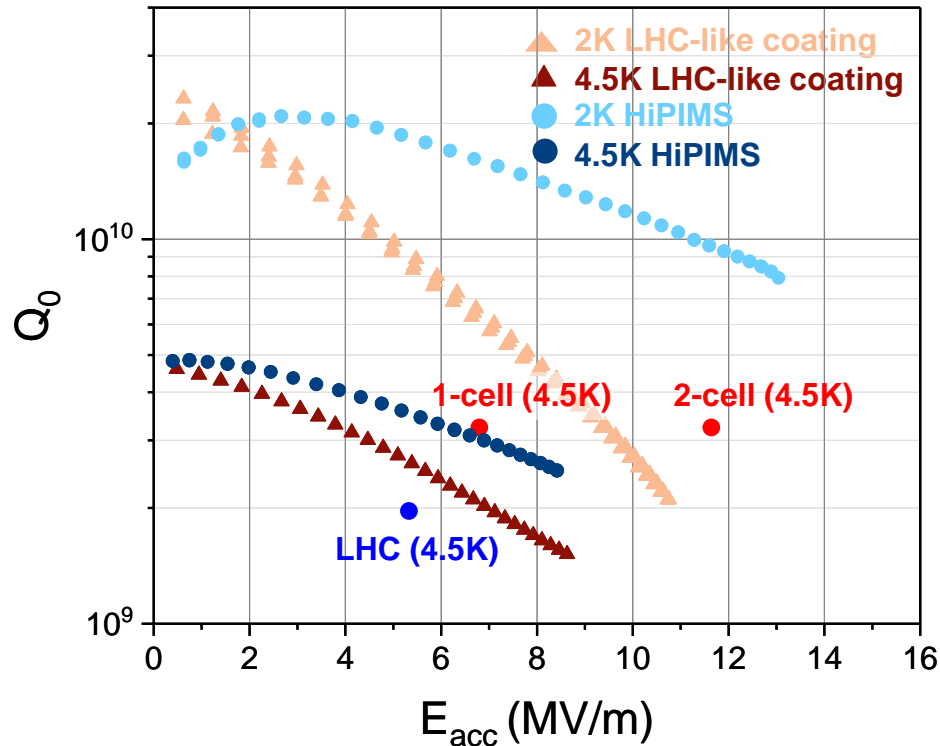


# 400 MHz HiPIMS: results



- Improved Q-slope and no field emission up to tested values.
- Approaching FCC-ee 1-cell target (no HOM ports)

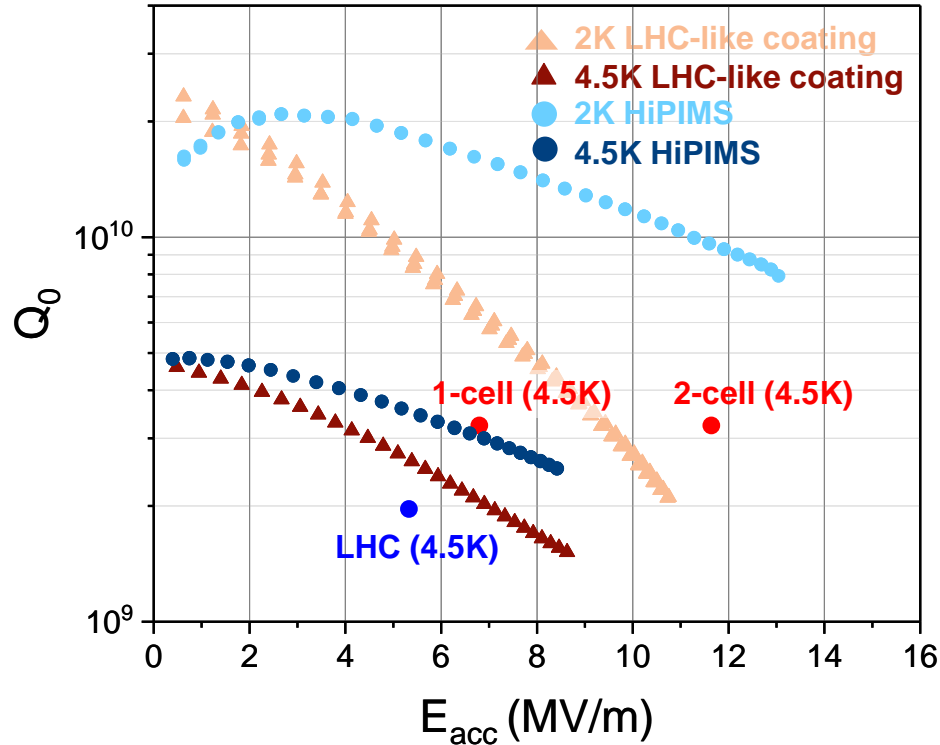
# 400 MHz HiPIMS: results



## Very promising result:

- PC04 is not a seamless substrate
- Treated by SUBU instead of EP.
- Coating done with Bipolar HiPIMS (HiPIMS + PP, DC biasing was not yet possible)
- HiPIMS coating validated, yet to be optimized (power supply limitation)

# 400 MHz HiPIMS: goals



Reach FCC 2-cell target



Electropolished surfaces, seamless substrates & optimised HiPIMS coating parameters.



# ROADMAP

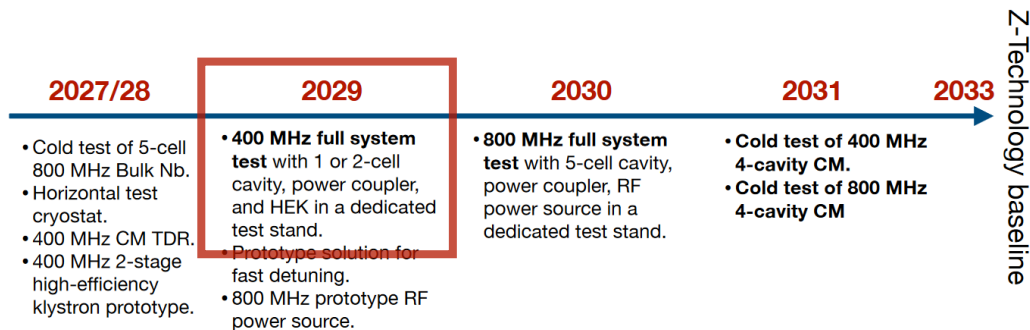
Scale up optimization done on 1.3 GHz to 400 MHz 1-cell and 2-cell

# Going forward

Continue fundamental study on samples and 1.3 GHz cavities to optimize coating recipe



## Upcoming RF milestones within the next years



SRF Roadmap, F. Gerigk, SRF workshop 2024

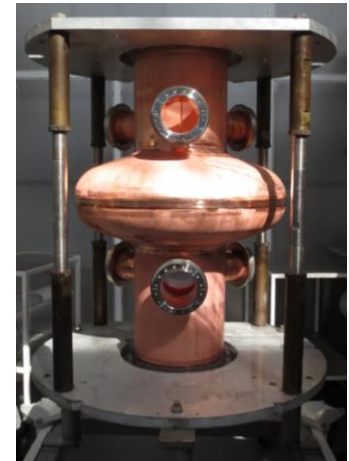
**Prioritize coatings and RF measurements of 400 MHz cavities**

# 400 MHz roadmap

- 2024, 3 RF measurements (Aug, Oct and Nov)
- Scale up simplified cavity to 1-cell configuration



400 MHz simplified cavity



400 MHz cavity



# 400 MHz roadmap

- Scale up simplified cavity to 1-cell configuration

1. **EP + HiPIMS PP**  
(cavity w/o HOM ports)

EP surface treatment (instead of SUBU)

**To be first qualified on a cavity Q3 2024**



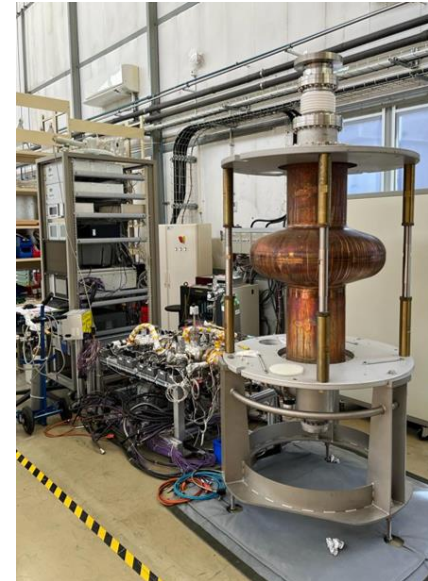
# 400 MHz roadmap

- Scale up simplified cavity to 1-cell configuration

1. **EP + HiPIMS PP**  
(cavity w/o HOM ports)

EP surface treatment

Coating with optimized parameters for Bipolar HiPIMS  
(HiPIMS + PP)



# 400 MHz roadmap

- Scale up simplified cavity to 1-cell configuration



1. EP + HiPIMS PP  
(cavity w/o HOM ports)
2. EP + HiPIMS PP  
(cavity w/ HOM ports)

# 400 MHz roadmap

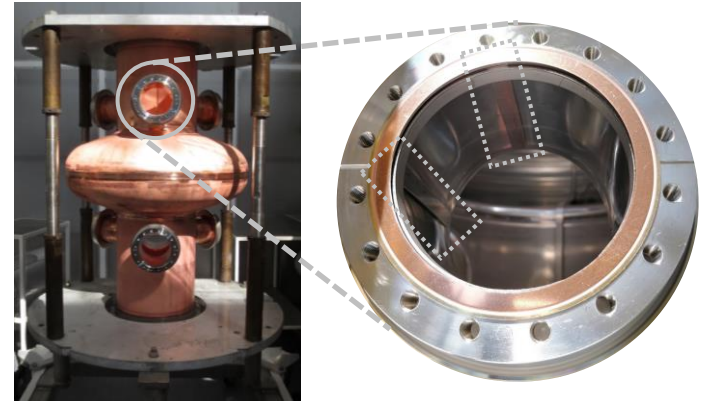
- Scale up simplified cavity to 1-cell configuration

1. EP + HiPIMS PP  
(cavity w/o HOM ports)

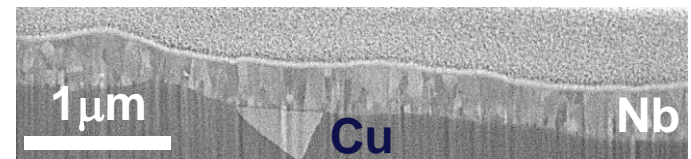
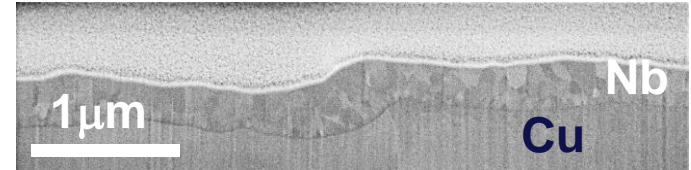
2. EP + HiPIMS PP  
(cavity w/ HOM ports)

Coating trial on samples done in 2020.

**Dense, defect free layers.**



HiPIMS + PP (+80 V)



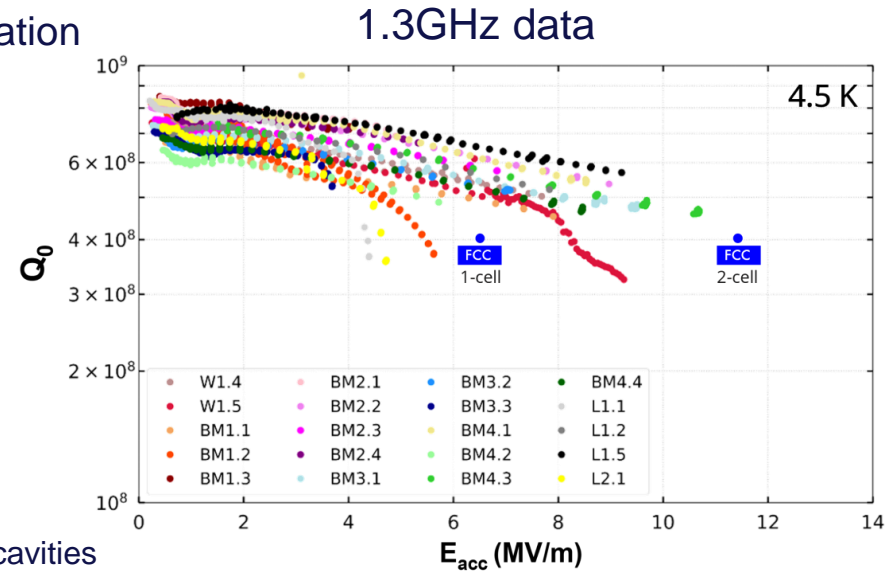
# 400 MHz roadmap

- Scale up simplified cavity to 1-cell configuration



1. EP + HiPIMS PP  
(cavity w/o HOM ports)
2. EP + HiPIMS PP  
(cavity w/ HOM ports)
3. EP + HiPIMS DC bias  
(cavity w/ HOM ports)

HiPIMS + DC bias as optimized for 1.3 GHz cavities



# 400 MHz roadmap

- Scale up simplified cavity to 1-cell configuration

1. EP + HiPIMS PP  
(cavity w/o HOM ports)

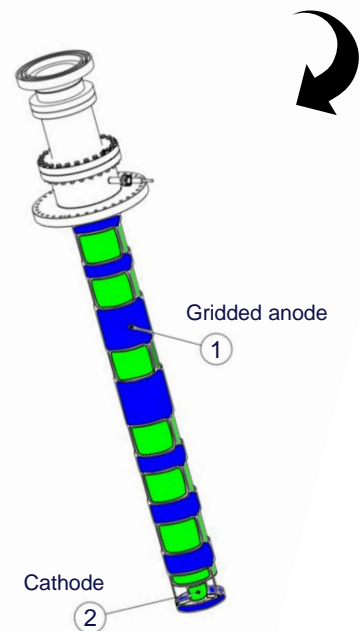
2. EP + HiPIMS PP  
(cavity w/ HOM ports)

3. EP + HiPIMS DC bias  
(cavity w/ HOM ports)

HiPIMS + DC bias as optimized for 1.3 GHz cavities

**Benchmark HiPIMS + DC bias with HiPIMS + PP**

Coating system needed to be modified to allow DC bias:  
parts under manufacturing



# 400 MHz roadmap

- Scale up simplified cavity to 1-cell configuration
- Seamless substrates

## 1. Bulk machined 400 MHz

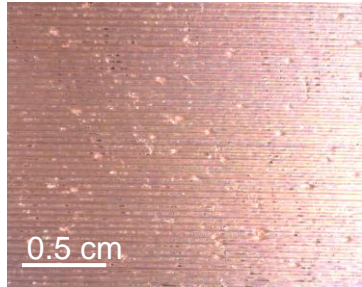


400 MHz Monoblock

# 400 MHz roadmap

- Scale up simplified cavity to 1-cell configuration
- Seamless substrates

## 1. Bulk machined 400 MHz



Surface state after machining



400 MHz Monoblock



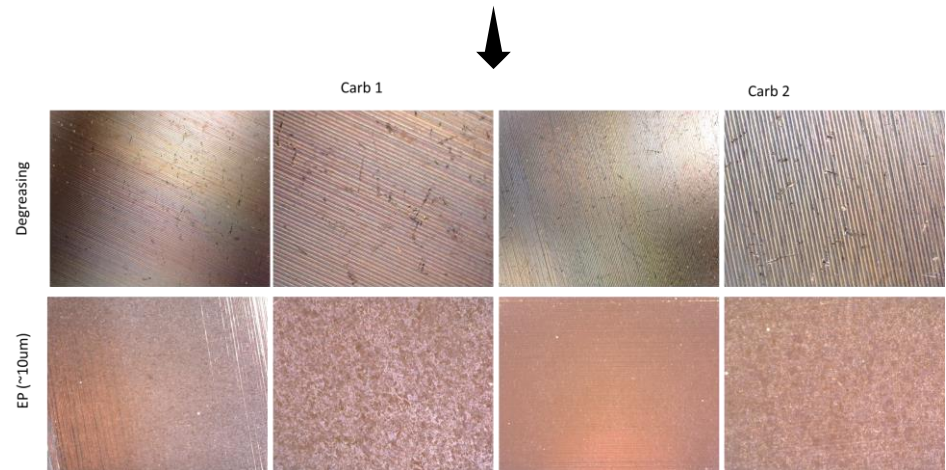
# 400 MHz roadmap

- Scale up simplified cavity to 1-cell configuration
- Seamless substrates

## 1. Bulk machined 400 MHz

Cu surface state after EP validated on samples

Samples made by the EN/MME group at CERN to replicate surface state



10  $\mu\text{m}$  EP efficiently removed the surface defects

# 400 MHz roadmap

- Scale up simplified cavity to 1-cell configuration
- Seamless substrates

## 1. Bulk machined 400 MHz

Cu surface state after EP validated on samples

EP and HiPIMS coating on finished substrate planned **2025**



400 MHz Monoblock

# 400 MHz roadmap

- Scale up simplified cavity to 1-cell configuration
- Seamless substrates

## 1. Bulk machined 400 MHz

## 2. Hydroformed (collaboration with KEK)

4 HiPIMS coatings done on 1.3 GHz cavities in early 2024  
(2 RF tests done at KEK, 4 RF tests to be done at CERN)

**Large scale production under study**



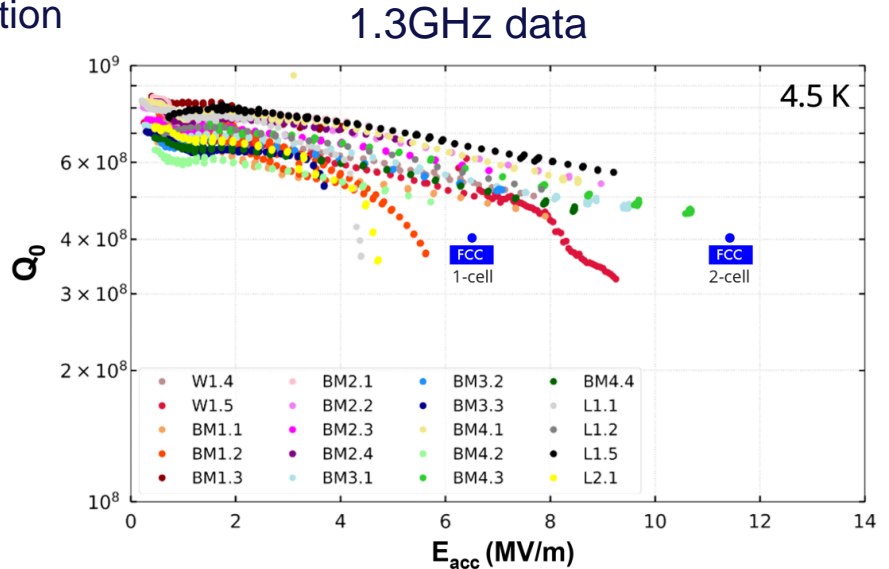
1.3 GHz hydroformed cavities

# 400 MHz roadmap

- Scale up simplified cavity to 1-cell configuration
- Seamless substrates
- 400 MHz 2-cell cavities

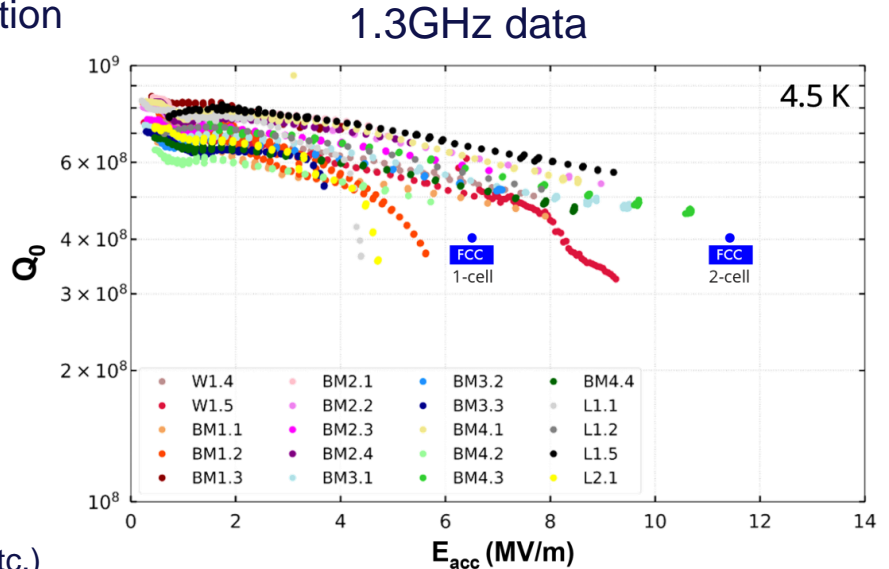
# 400 MHz roadmap

- Scale up simplified cavity to 1-cell configuration
- Seamless substrates
- 400 MHz 2-cell cavities
  1. 2-cell specs within reach at higher frequencies (1.3 GHz)



# 400 MHz roadmap

- Scale up simplified cavity to 1-cell configuration
- Seamless substrates
- 400 MHz 2-cell cavities
  1. **2-cell specs within reach at higher frequencies (1.3 GHz)**
  2. **2-cell cavity not yet available.**
    - Manufacture substrate
    - Design/update coating setup (new cathode, etc.)
    - Update EP bench
    - ...



# CRD+ 2025

- Goals for CDR+ 2025:
  1. **Reach FCC-ee 1-cell specifications simplified cavity**
    - Establish the surface treatment recipe
    - Define a Nb coating recipe
  2. **Reach FCC-ee 1-cell specifications cavity w/ HOM ports**
  3. **Assess maximum reachable performance:**
    - Bulk-machined 400MHz cavity
    - Electropolished substrate
    - Optimized coating recipe
    - 2-cells specification within reach?**



Thank you  
for your attention.