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HiPIMS coatings at CERN for SRF cavities

Current status and forecast

Eucard2 WP12 Annual Meeting, 14.03.2017, NCBJ Swierk

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Outline

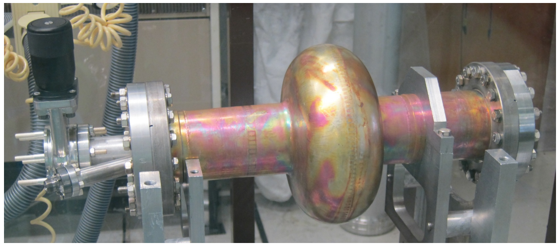
- HiPIMS
  - Motivation / principle
  - Setup
  - Samples coatings
  - Cavities coatings
  - Next steps
- Conclusion

HiPIMS motivation / principle

DCMS Limitations

- **D**irect **C**urrent **M**agnetron **S**puttering
- Historical method used at CERN for SRF Nb/Cu

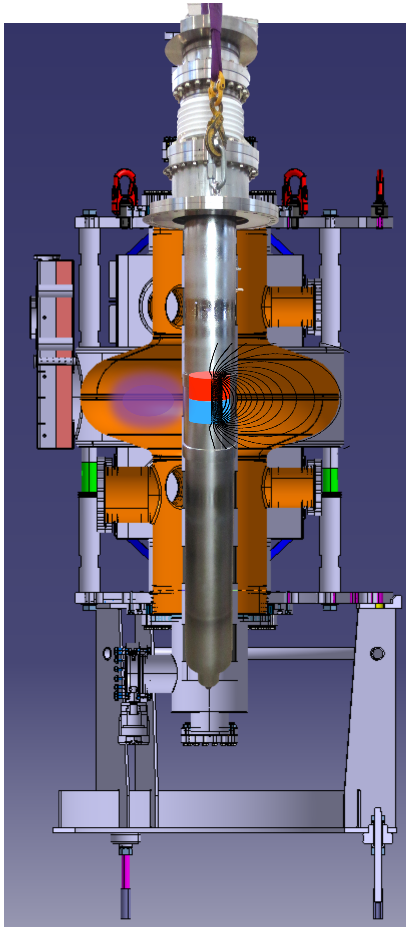
LEP cavity



1.3 GHz cavity

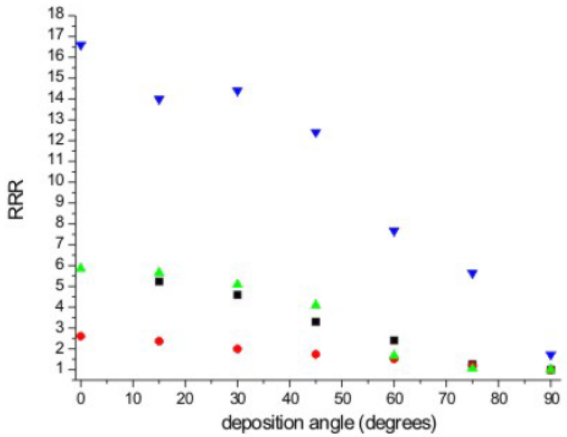
LHC cavity

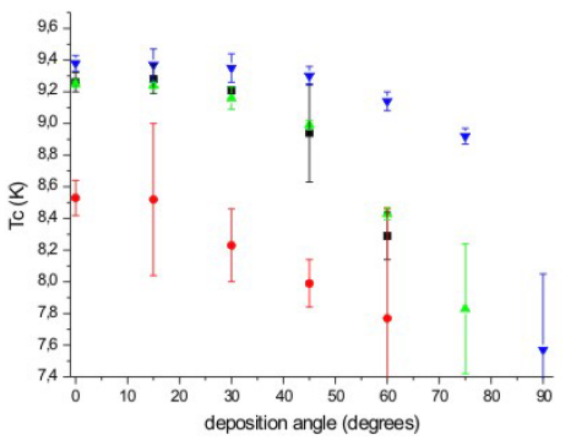
- Target made of raw material (Nb RRR 300)
- Ultrapure Ar or Kr
- UHV (5.10^{-10} mbar base pressure)
- High coating rate (up to 100's nm/min)



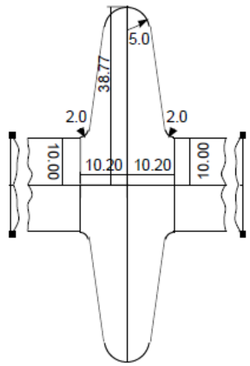
DCMS Limitations

Samples [1]

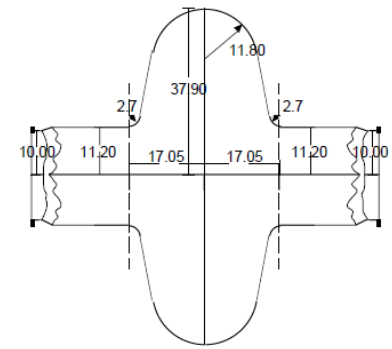




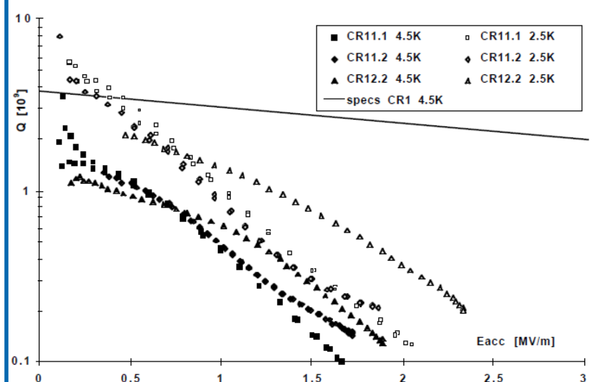
352 MHz Cavities [2]

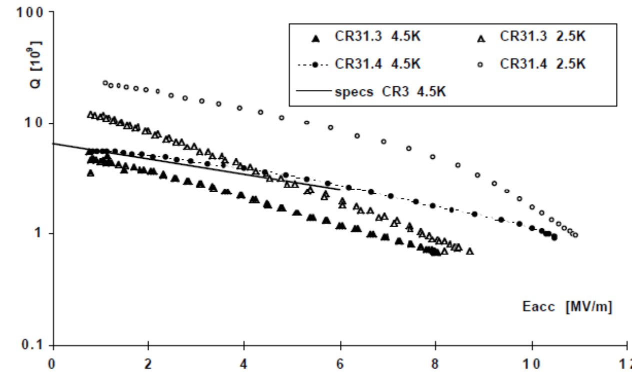


$\beta = 0.48$



$\beta = 0.8$



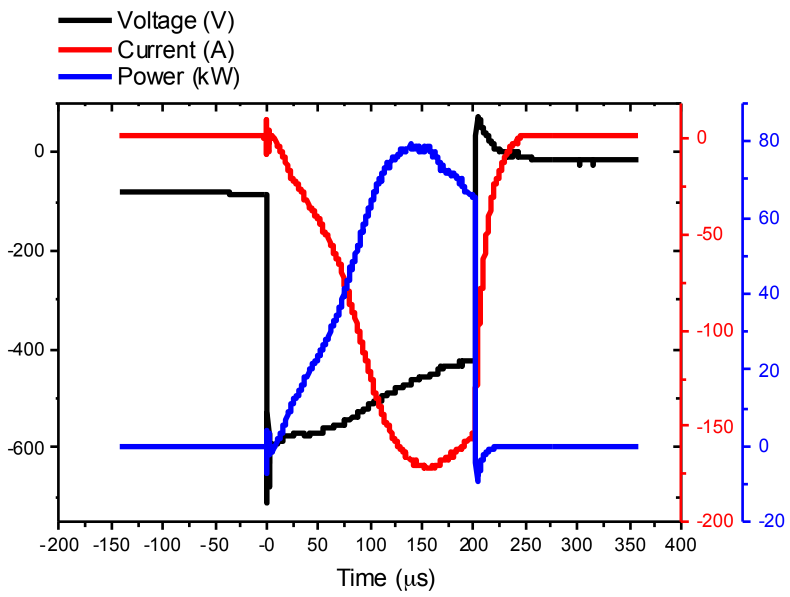


[1] D. Tonini et al, Morphology of niobium films sputtered at different target-substrate angle, 11th workshop on RF superconductivity, THP11
[2] C. Benvenuti et al, Production and test of 352 MHz Niobium Sputtered Reduced Beta cavities, 1997, SRF97D25

Principle

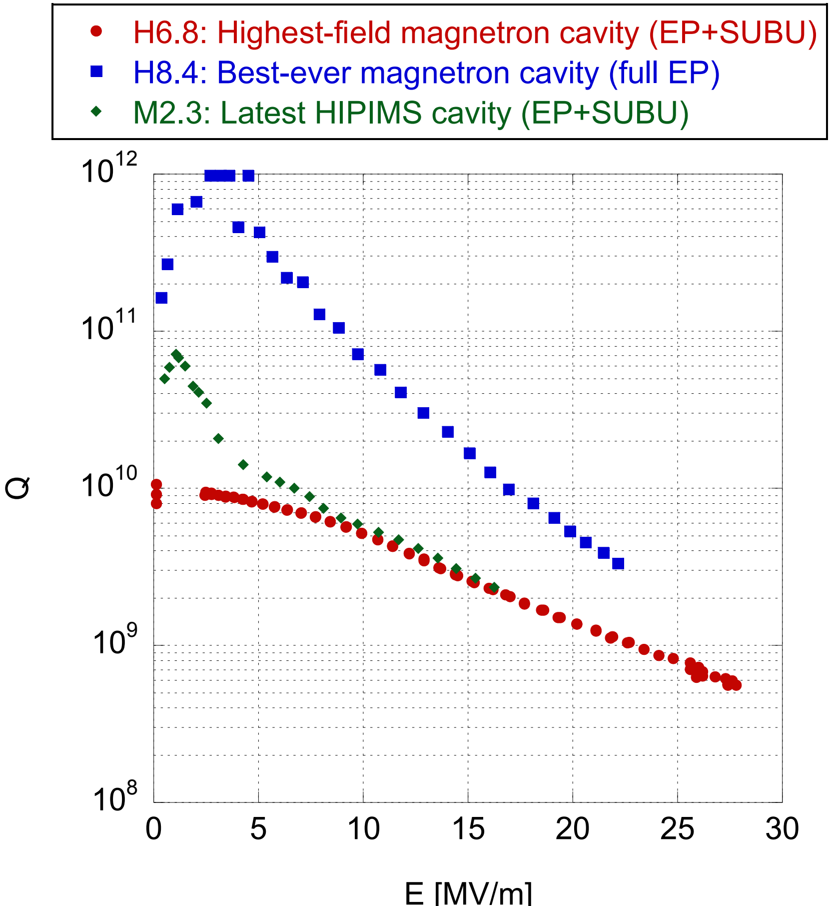
- **HI**gh **P**ower **I**mpulse **M**agnetron **S**puttering

- Pulsed power supply (~100μs pulses, 1% duty cycle up to 1kHz)
- Power density
  - DC: 12 W.cm^{-2}
  - HiPIMS: ~1kW.cm^{-2}
- Ionization of sputtered species up to 90%
- Better coating conformity
- Lower substrate self heat-up
- Lower coating rate : ions captured at the cathode
- Very sensitive to cathode surface state (roughness) → arcing



Motivation

- Encouraging first coating (G. Terenziani, 2013)



HiPIMS performs close to the best ever achieved magnetron coated cavities.

How to go farther?

HiPIMS Setup @ CERN

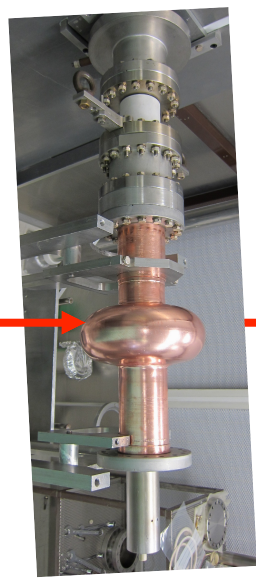
HiPIMS setup for 1.3 GHz cavities coating

- Base pressure ~ 6.10^{-10} mbar
- Nb cathodes and anodes (cut-off coating)
- Cell coating by HiPIMS + Bias using Kr
- → Process capabilities of 1 cavity/2weeks

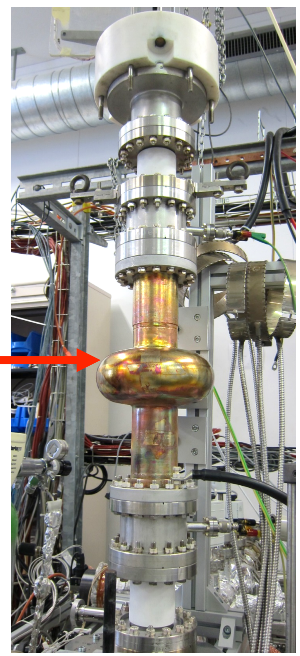
High **P**ower **I**mpulse **M**agnetron **S**puttering

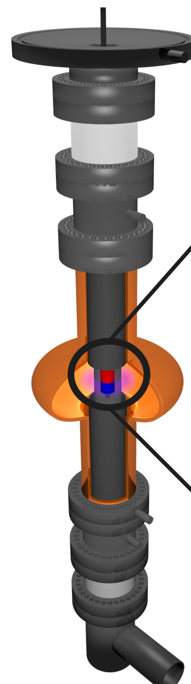
- Same hardware as for DCMS
- Pulsed Power supply
  - 1% duty cycle
  - Short pulses: 200 μs
  - High peak current (200 A vs 3 A DCMS)
  - High peak power (80 kW peak for 1kW avg)
  - Ionization of sputtered species
    - → Lower coating rate

Nb cathode



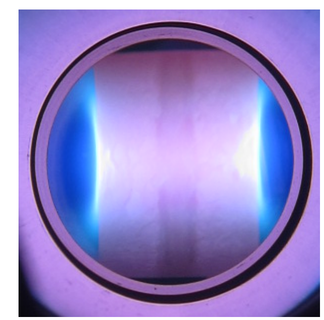
1.3 GHz cavity





1.3 GHz cavity coating setup

Nb cathode with permanent magnets inside and Nb anodes



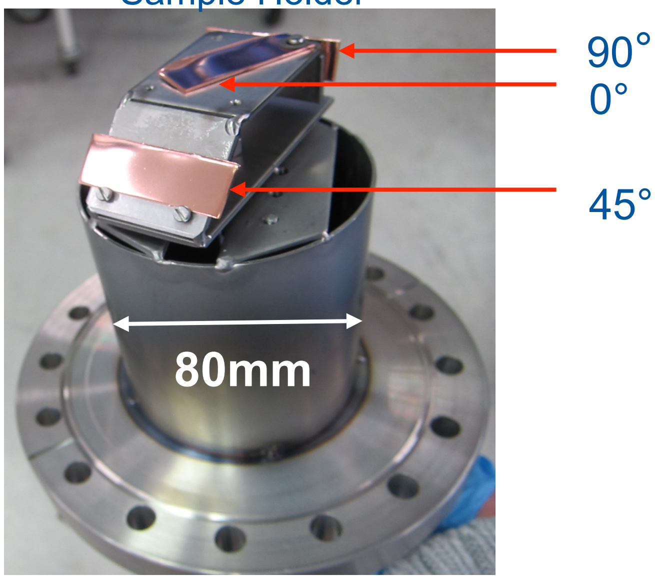
HiPIMS discharge

Samples types

2 types

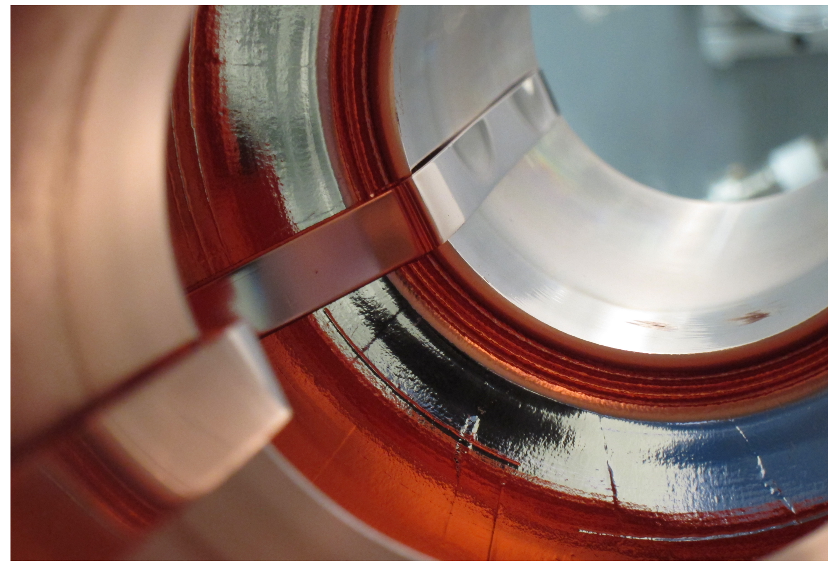
- Small samples

Sample Holder



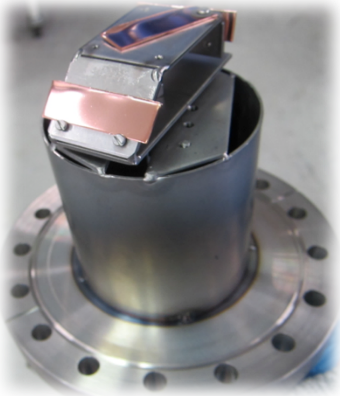
- Easy mounting
  - No need of dismounting the coating chamber
- Local
  - Not representative of cavity behavior

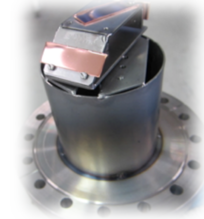
- Cavity replica



- Cavity exact shape
  - Reproduces the internal surface of the cavities
- Mounting
  - As complicated as a cavity mounting

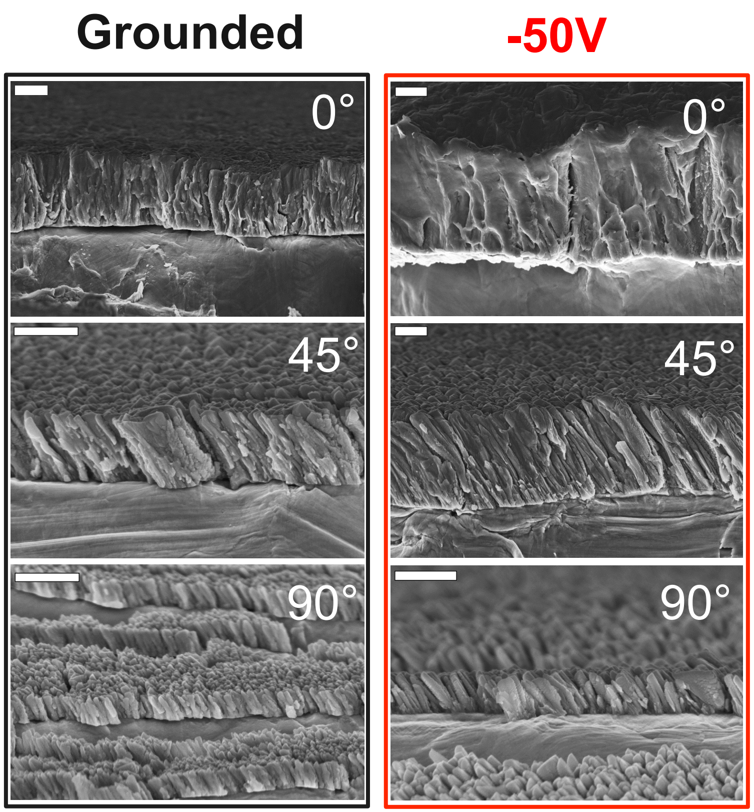
Small samples - results





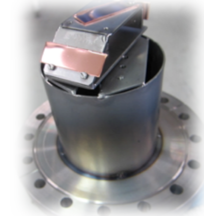
Impinging angle effect

DCMS COATINGS



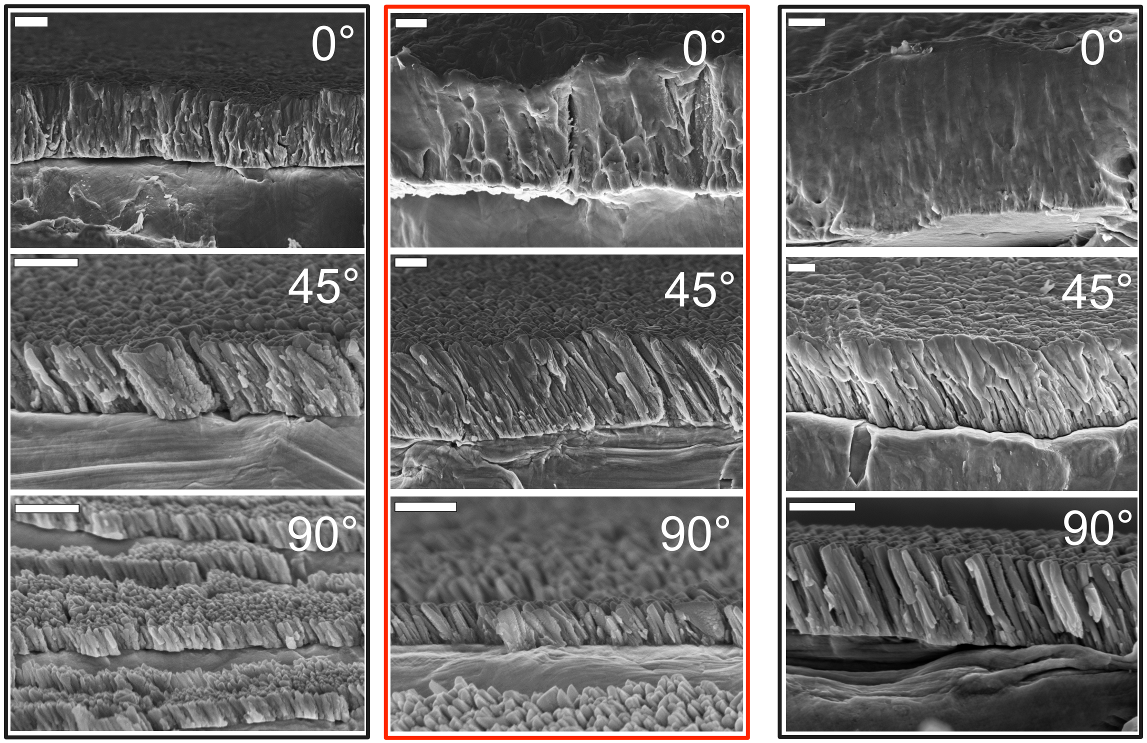
- No major improvement from grounded to biased DCMS

Impinging angle effect



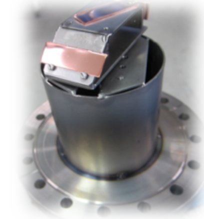
DCMS COATINGS | **HiPIMS COATINGS**

Grounded | **-50V** | **Grounded**



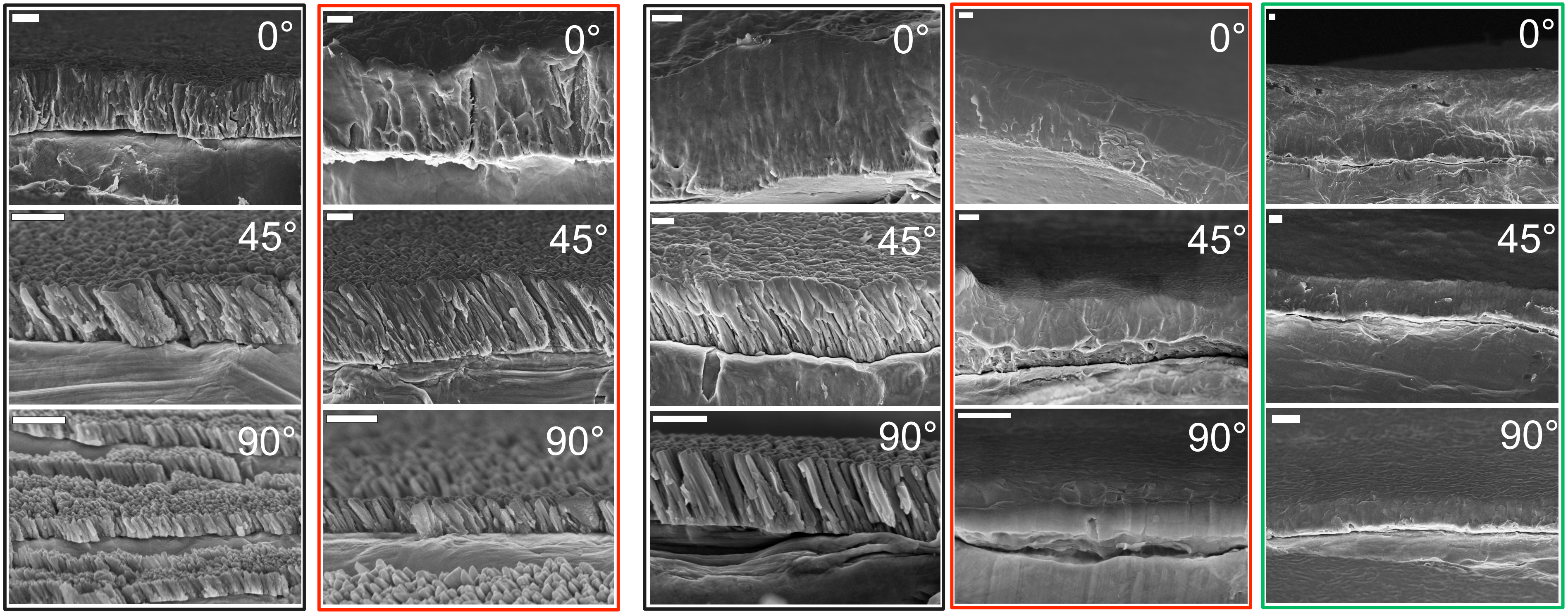
- No major improvement from grounded to biased DCMS
- Grounded HiPIMS equivalent to DCMS

Impinging angle effect



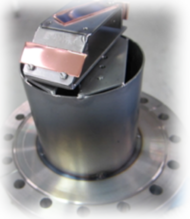
DCMS COATINGS — **Grounded** | **-50V**

HiPIMS COATINGS — **Grounded** | **-50V** | **-100V**

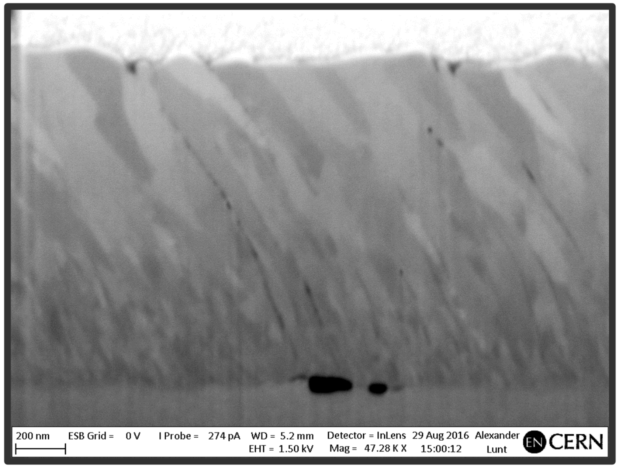


- No major improvement from grounded to biased DCMS
- Grounded HiPIMS equivalent to DCMS
- Biased HiPIMS shows densification of the layer no matter the orientation

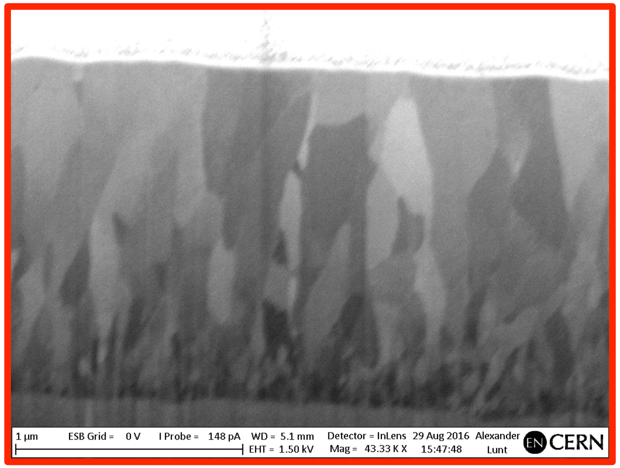
Impinging angle effect



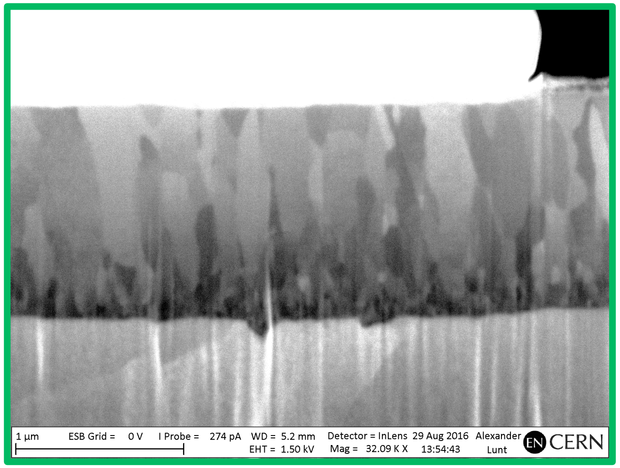
Grounded



-50 V



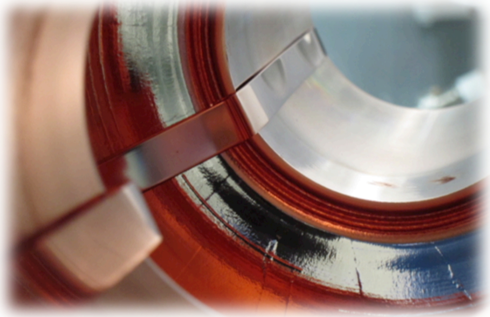
-100 V



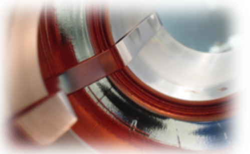
FIB cross sections confirm the bias effect.
Porosities visible on grounded sample.
A soon as the substrate is biased the layer densifies exhibiting no porosities

Cavity replica samples

Study example



Frequency effect



Constant power, pressure and pulse width:

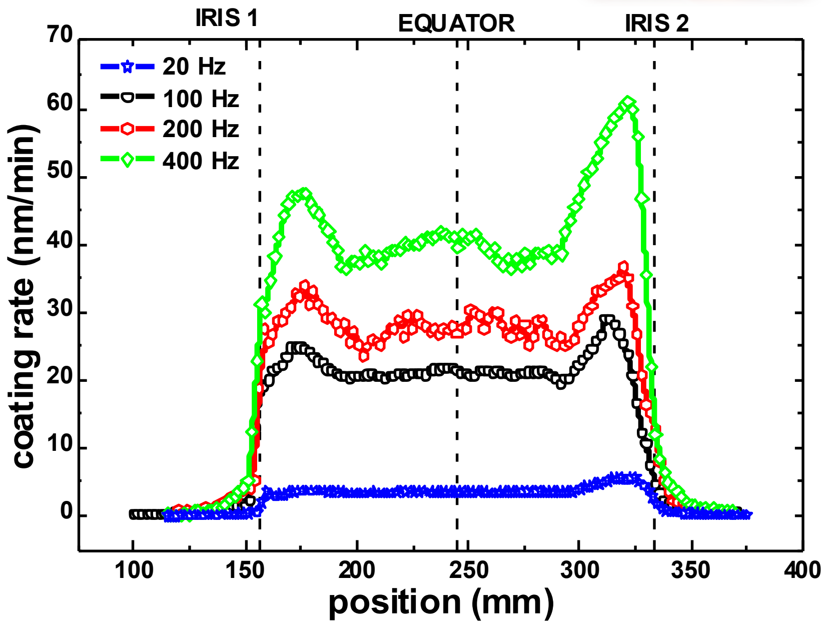
1.3 kW avg, 2.10^{-3} mbar, 200μs

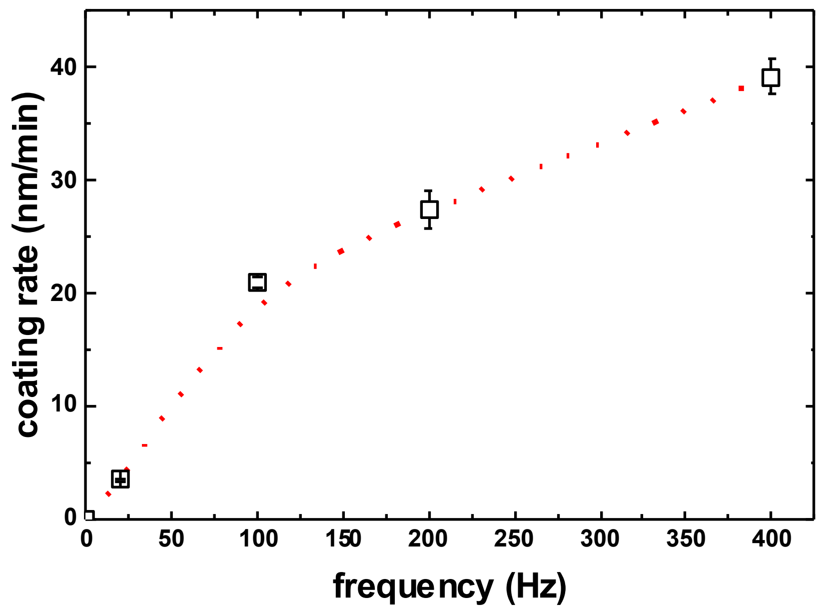
Constant average power
↑ Frequency and cst pulse → ↓Peak power

Reduced ionization ratio of Nb
Increased coating rate → lower contamination

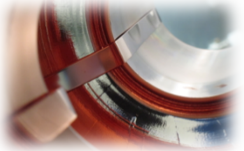
Good for RF? To be measured on cavities

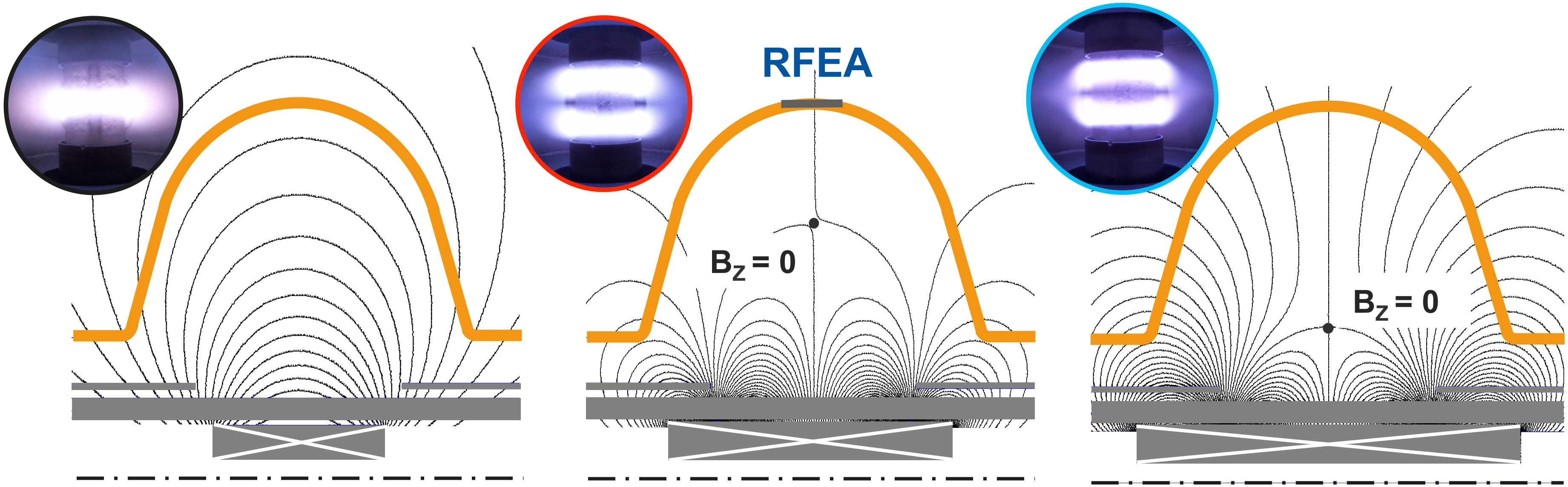
Also carried on:
- Pulse width effect
- Pressure effect
- Peak power effect

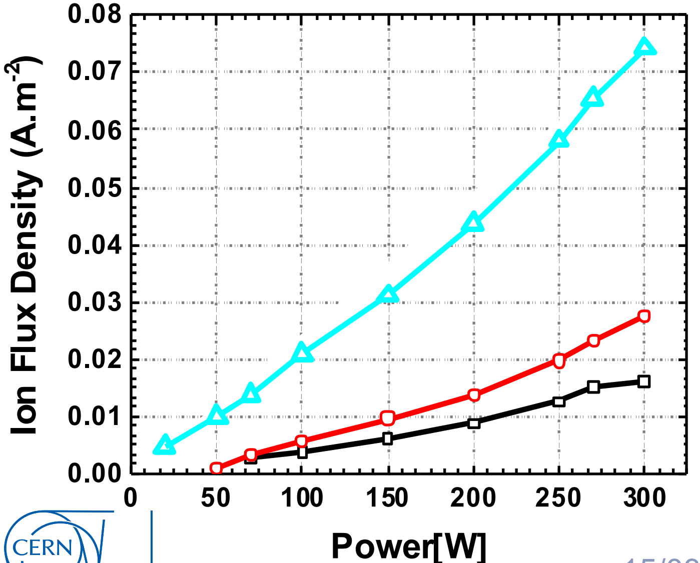




Magnetic assembly

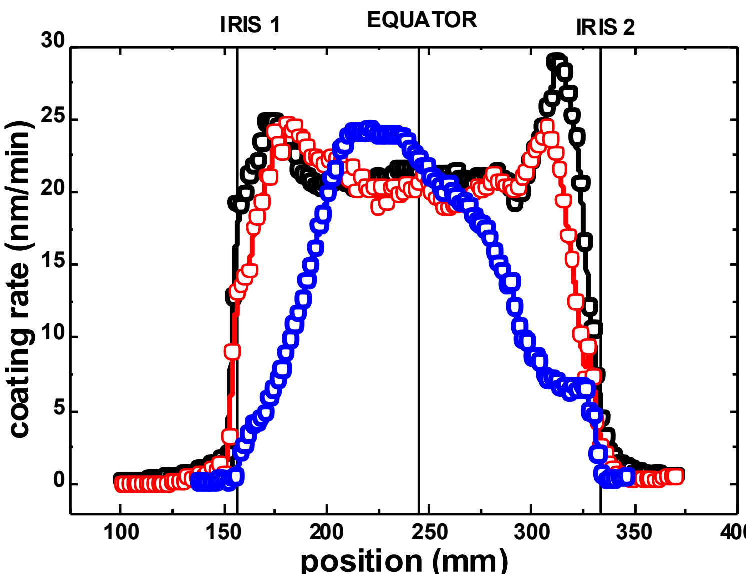






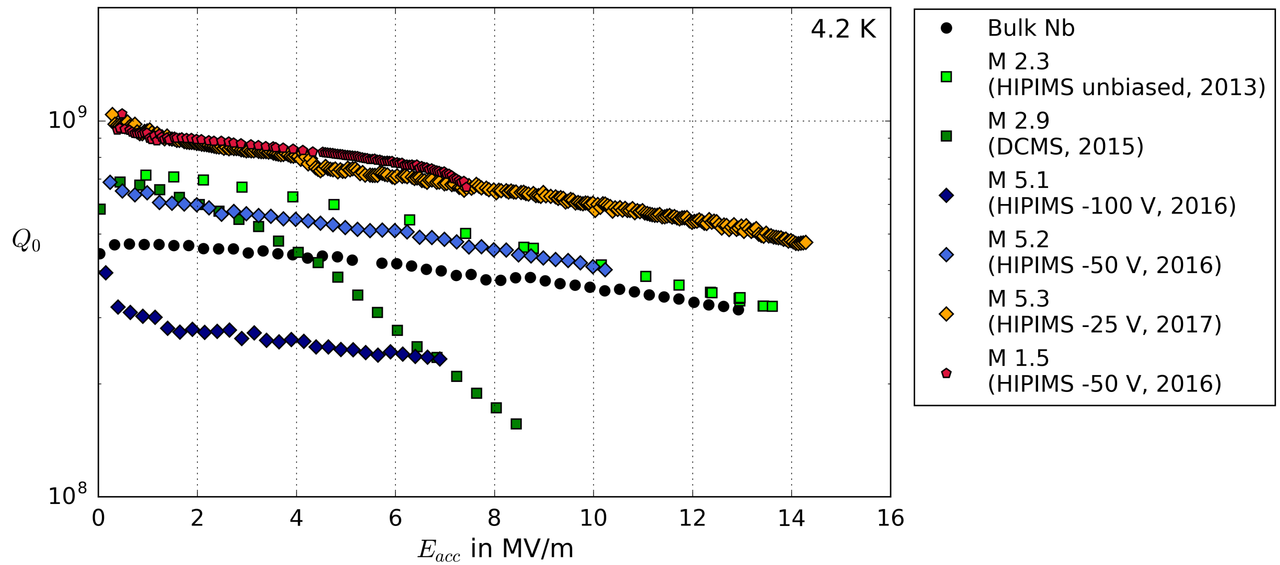
Modulation of the ion flux density

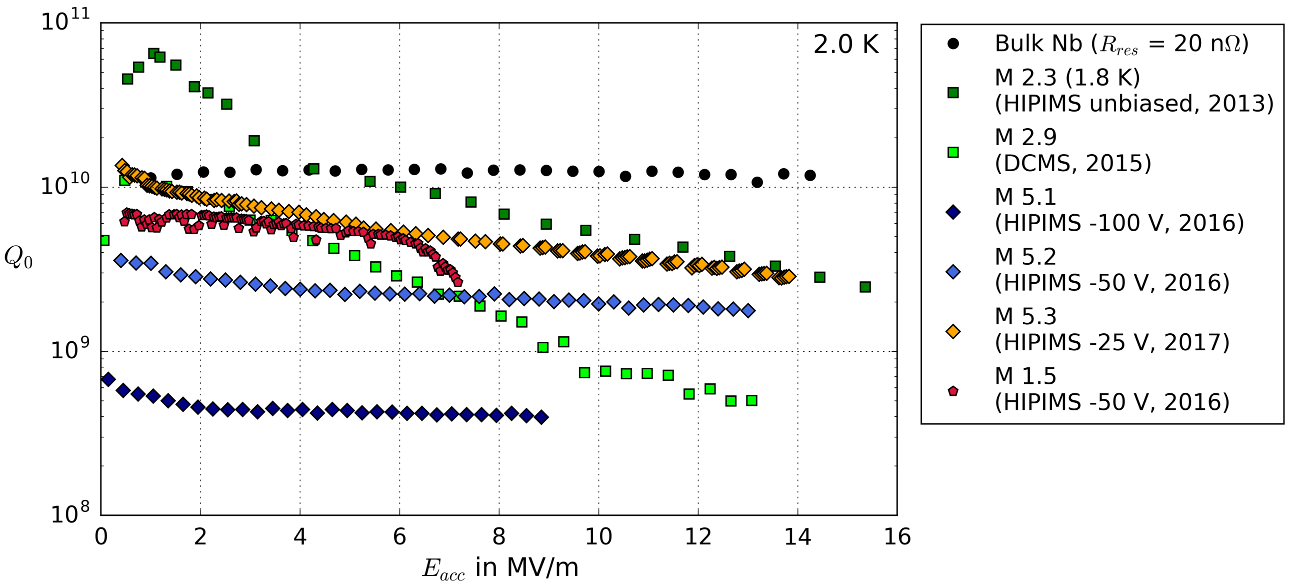
Possibility to change the coating profile in HiPIMS



Cavities coatings

RF performances





12 cavities coated in 2016. 4 measured (adhesion issues)

Coating pressure and bias have shown a strong Q impact.

Q slope looks flatten compared to DCMS

Up to now best R_{res} = 25 nΩ

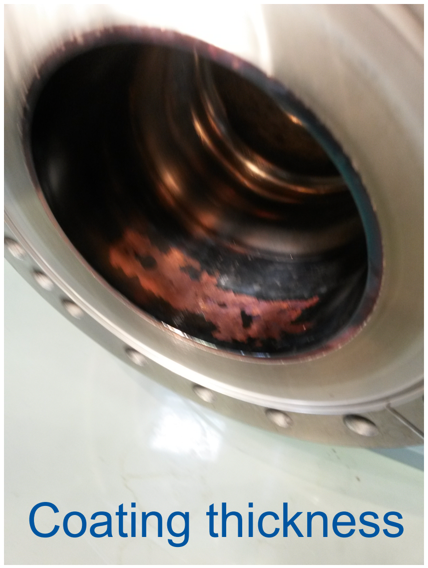
Poor substrates quality

10 new substrates delivered @ CERN

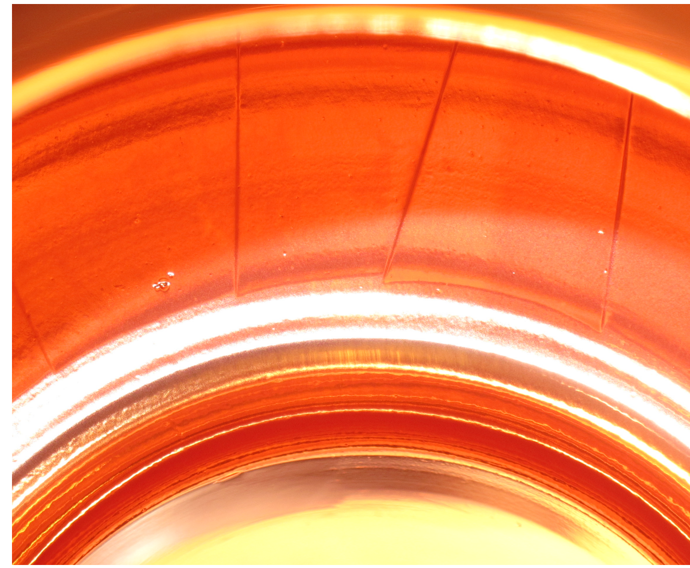
Discrepancy between cut-offs and cell behaviour
→ Investigations on going

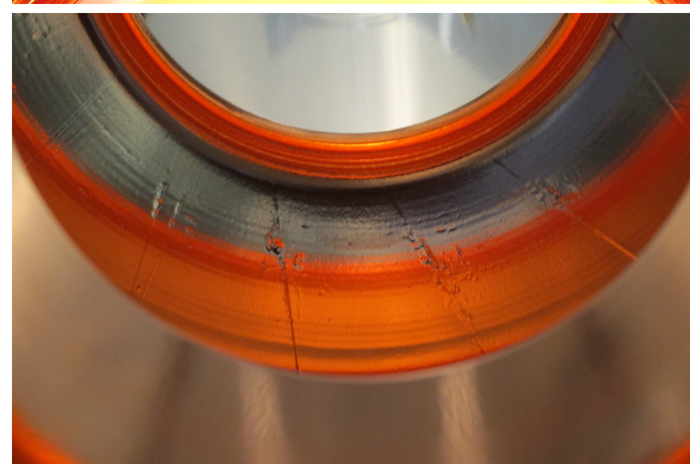
Issues

Peel-off



Substrate defects





Next steps

- Samples
  - FIB investigations on cavity replicas
  - Roughness vs coating parameters
  - Residual stress and micro-strain vs coating parameters
  - Tc vs coating parameters and position along the cavity

- Cavities
  - Continue exploring the coating parameters impact on RF performances
    - Important space of parameters
  - Evaluate the potential of coating low beta cavities
  - Coat a “good” substrate (a.k.a. M2)

SUMMARY

- Setup fully operational
  - 2 cavities/month
  - 2 cavities replica sample / week
- Very encouraging results
- More parameters to investigate
- Cavities performances trending up
- Project part of FCC WP3

Thank you for your attention