CERN

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Production and R&D thin films activities at CERN for SRF applications

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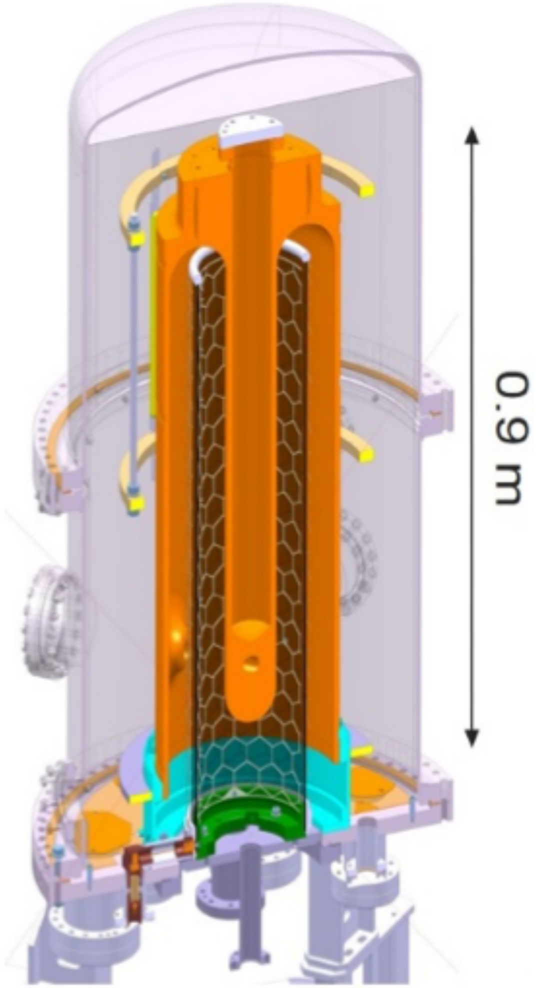
Outline

- Production
  - HIE-ISOLDE
  - LHC spares program
- R&D
  - HiPIMS
  - A15 Materials
- Conclusion / Perspectives

Production

HIE-ISOLDE

Coating Setup



Diode sputtering

Cylindrical Nb cathode

0.2 mbar working point

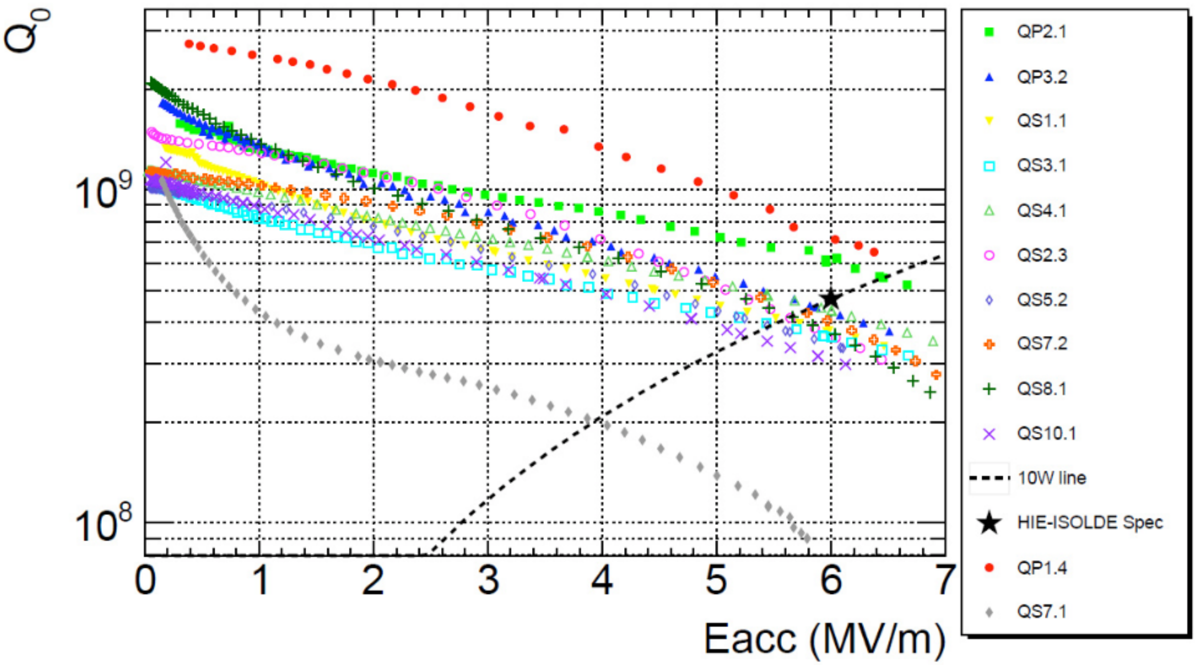
14 successives coatings steps

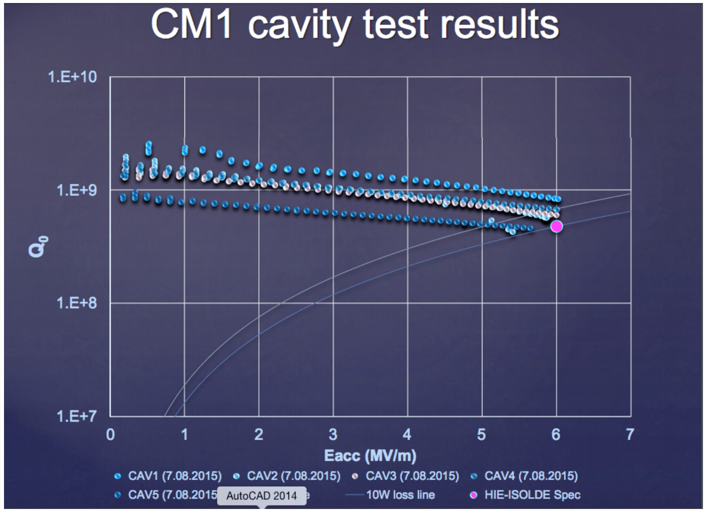
From 300°C to 650°C

CMs status

- CM1 : beam comissionning in Sep 2015
  - After physics run went back in cleanroom to fix coupler issue
  - Rinsing of the single cavity showing FE
- CM2: assembly finished
- CM3: to be completed by Sep-Oct 2016

- Beam comissionning on-going with both CM installed





Thin film quality

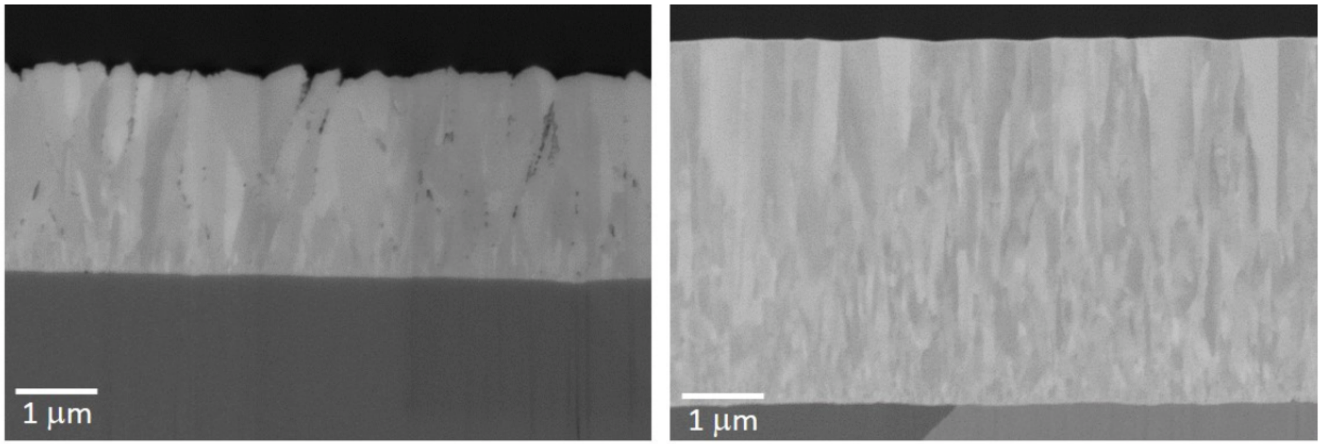


FIG. 3: FIB-SEM cross section images of HIE-ISOLDE coating at the top of the cavity with -80V bias (left) and -120V bias + wide cathode (right) showing the densification of the layer.

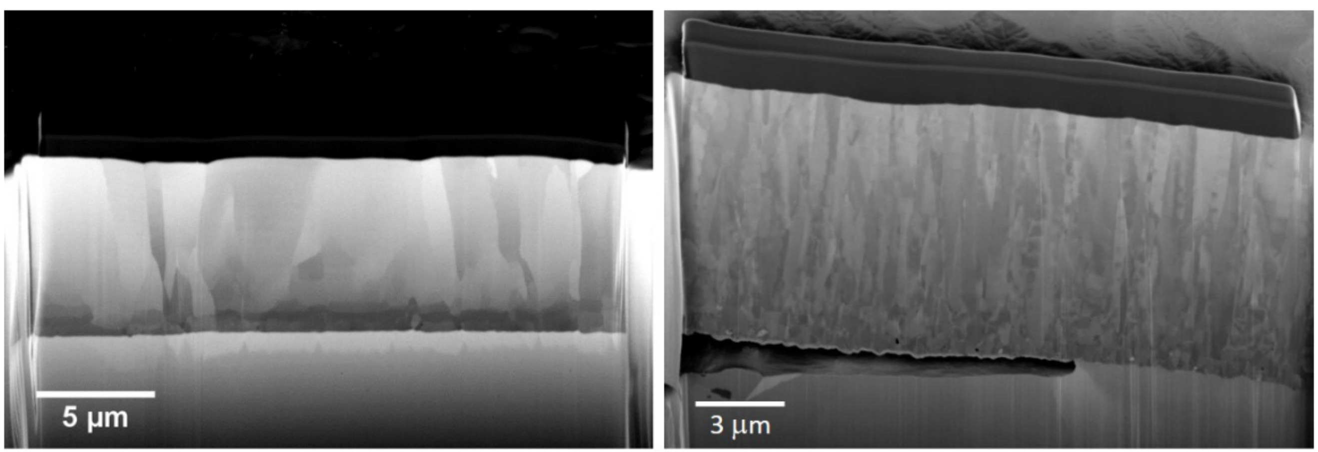


FIG. 4: FIB-SEM cross section images of HIE-ISOLDE coating at the middle of the antenna with -80V bias (left) and -120V bias (right) showing the delamination of the layer.

Thermal Model

- Q-slope supposed to be due to poor Nb/Cu thermal contact
  - Inverse problem → distribution function of thermal boundary resistances

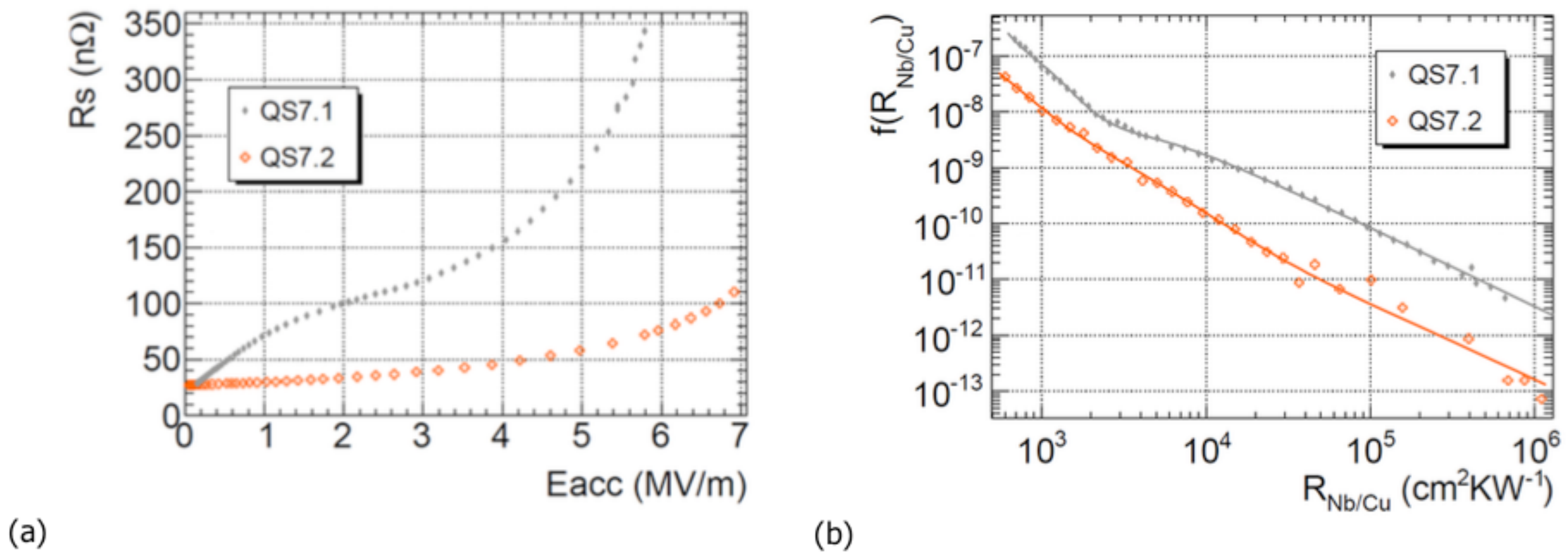


FIG. 8: (a) Rs(E_{acc}) curves of coatings QS7.1 and QS7.2 (see text). (b) Distribution function $f(R_{Nb/Cu})$ as a function of interface thermal impedance $R_{Nb/Cu}$ for coatings QS7.1 and QS7.2. The lines are only intended as a guide for the eye.

- Paper submitted: Performance analysis of the HIE-ISOLDE SRF cavities

THIN FILM WORKSHOP – JLAB 27-28-29 Jul

Production

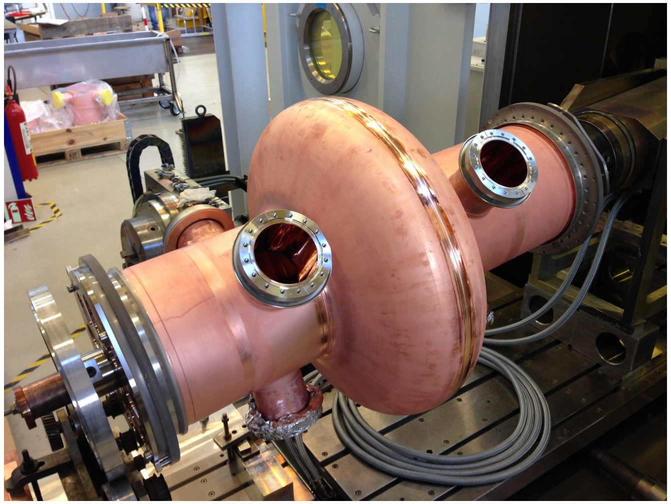
LHC Spares Program

Objectives

- Reproduce original LHC cavities specs
  - Q0 ≥ $4.5.10^9$ @ 0.5 MV/m
  - Q0 ≥ 2.10^9 @ 5 MV/m
- 1 spare cavity train by LS2 (end 2018)
  - Afterwards: 1 second set of cavities
- Investigate the use of EHF (Bmax) and spun/machined half-cells (Heggli).

Where are we?

- 2 new prototype cavities PC01 and PC02 manufactured @ CERN
- Not machine compatible but used to assess coating, procedures, infrastructures etc…



- Coating setup fully operational
  - 2014/2015: set-up of the coating bench and commissioning.
  - 2016: first coatings on two cavities PC01 and PC02 both to be measured.

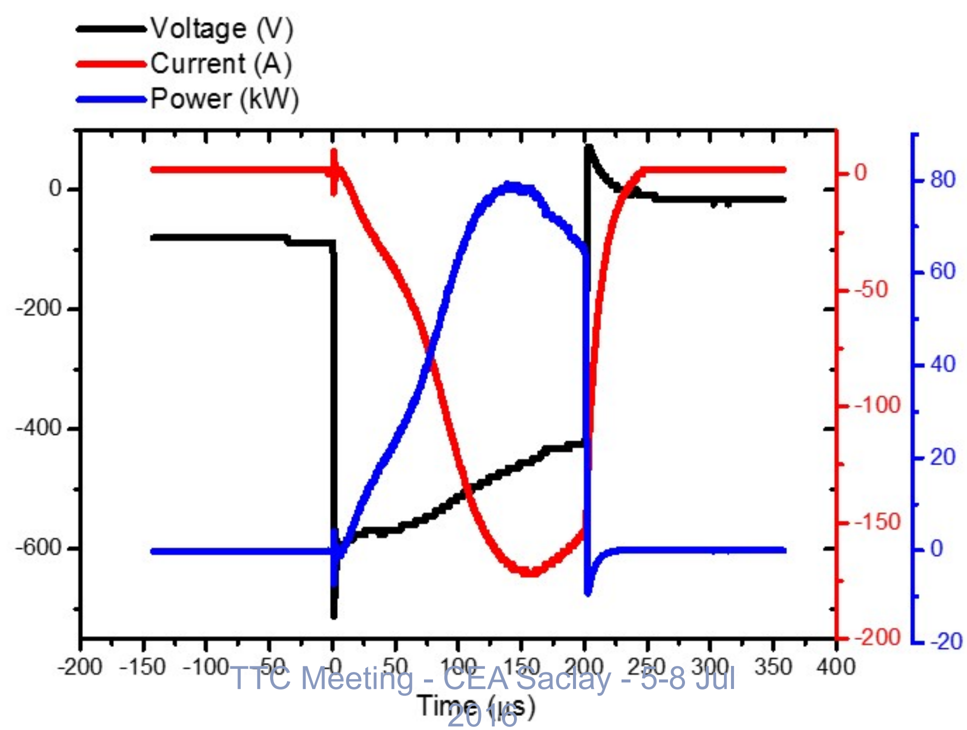
R&D activities

HiPIMS

HiPIMS coating

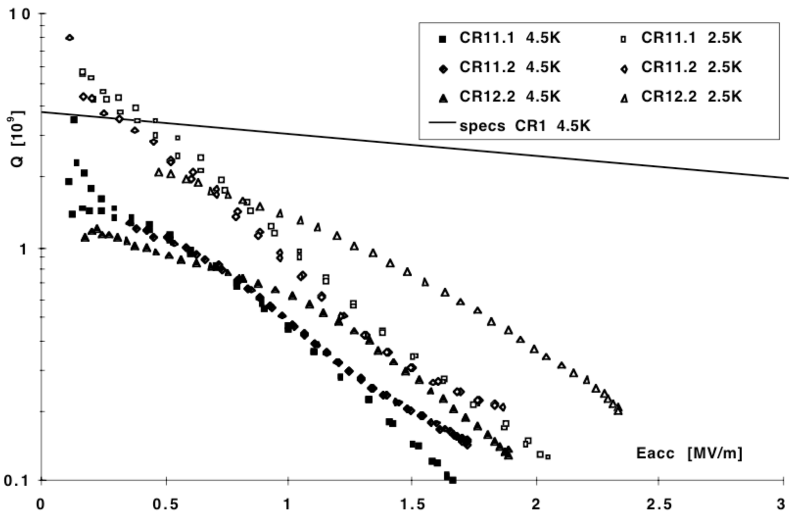
- **High** **P**ower **I**mpulse **M**agnetron **S**puttering
- High peak power with low duty cycle ~ 1%
  - Voltage ~ 2x DCMS
  - Current peak ~ 2 A.cm^{-2} (DCMS ~ 4 mA.cm^{-2})
- Ionization of sputtered species (Nb+, Nb++)
- Low coating rate (ions recaptured at the cathode)

- Parameters
  - Pulse duration
  - Repetition rate
  - Peak current



Challenges / Goals

- Mitigate cavity shape effect of thin film morphology / properties



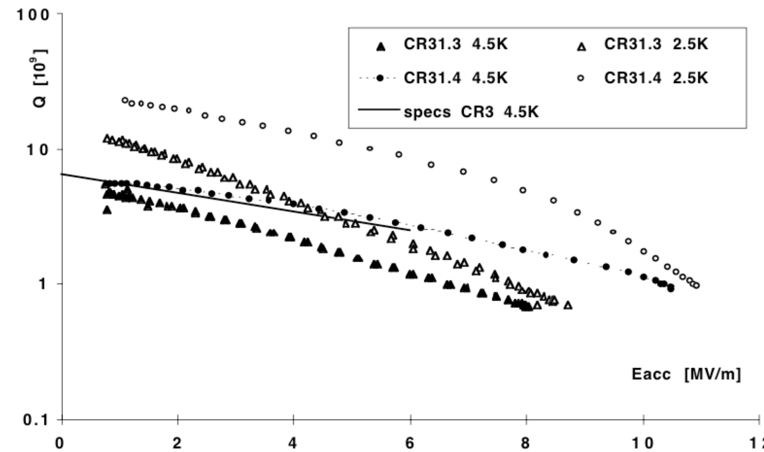
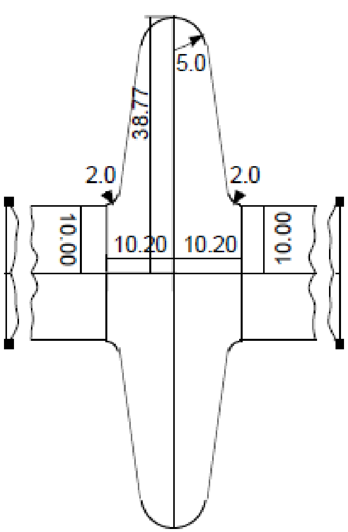
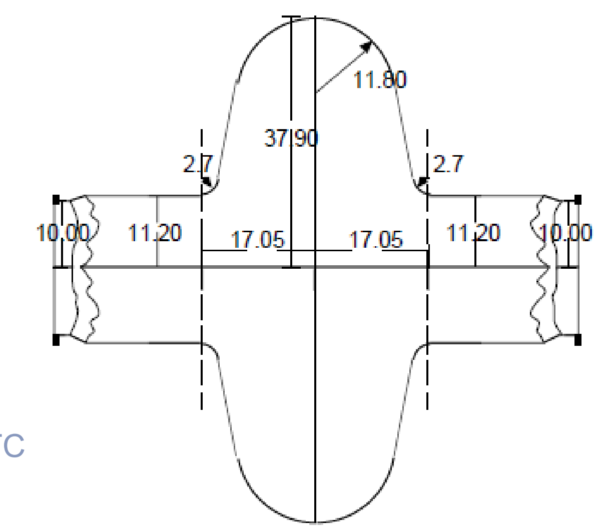


Fig. 4 : Q(E) of the ß=0.8 cavity at 4.5 (full) and 2.5 K (hollow)

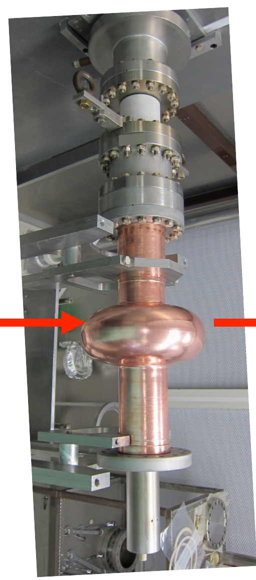




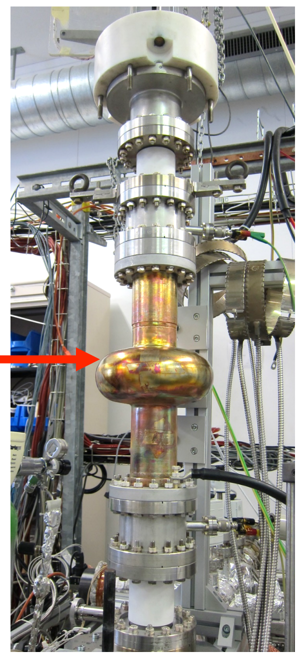
HiPIMS Setup @ CERN

- Typical base pressure after BO (150°C 48h) ~ 6.10^{-10} mbar
- Nb cathode and anodes (cut-off coating)
- Cut-off coating: DCMS, grounded cavity
- Cell: HiPIMS + Bias

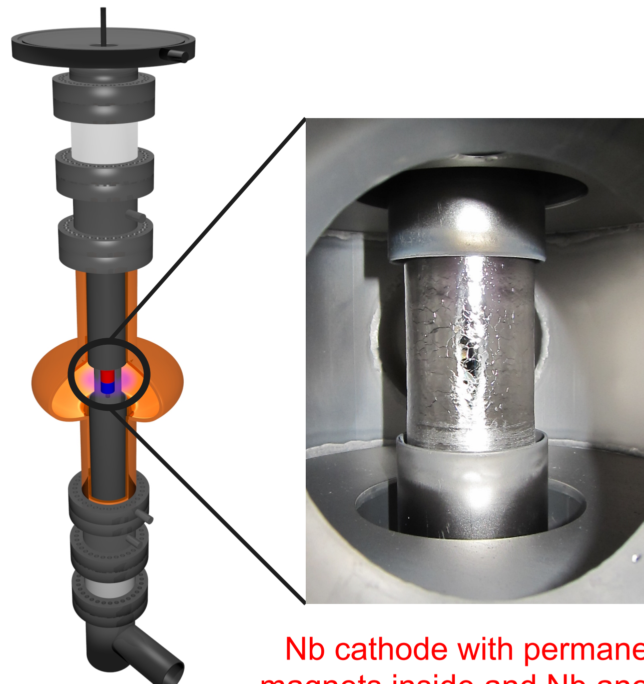
Nb cathode



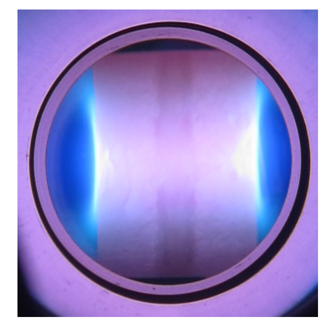
1.3 GHz cavity



1.3 GHz cavity coating setup



Nb cathode with permanent magnets inside and Nb anodes



HiPIMS discharge

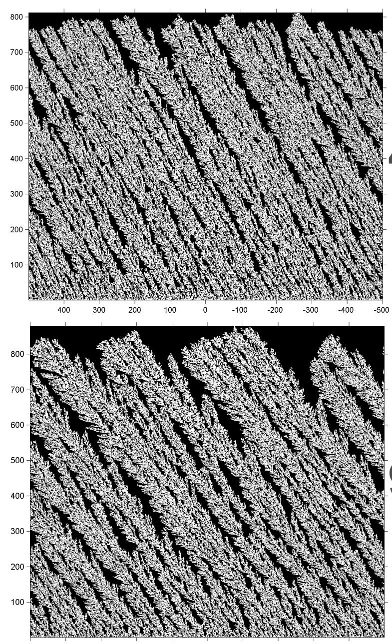
Impinging angle effect - DCMS

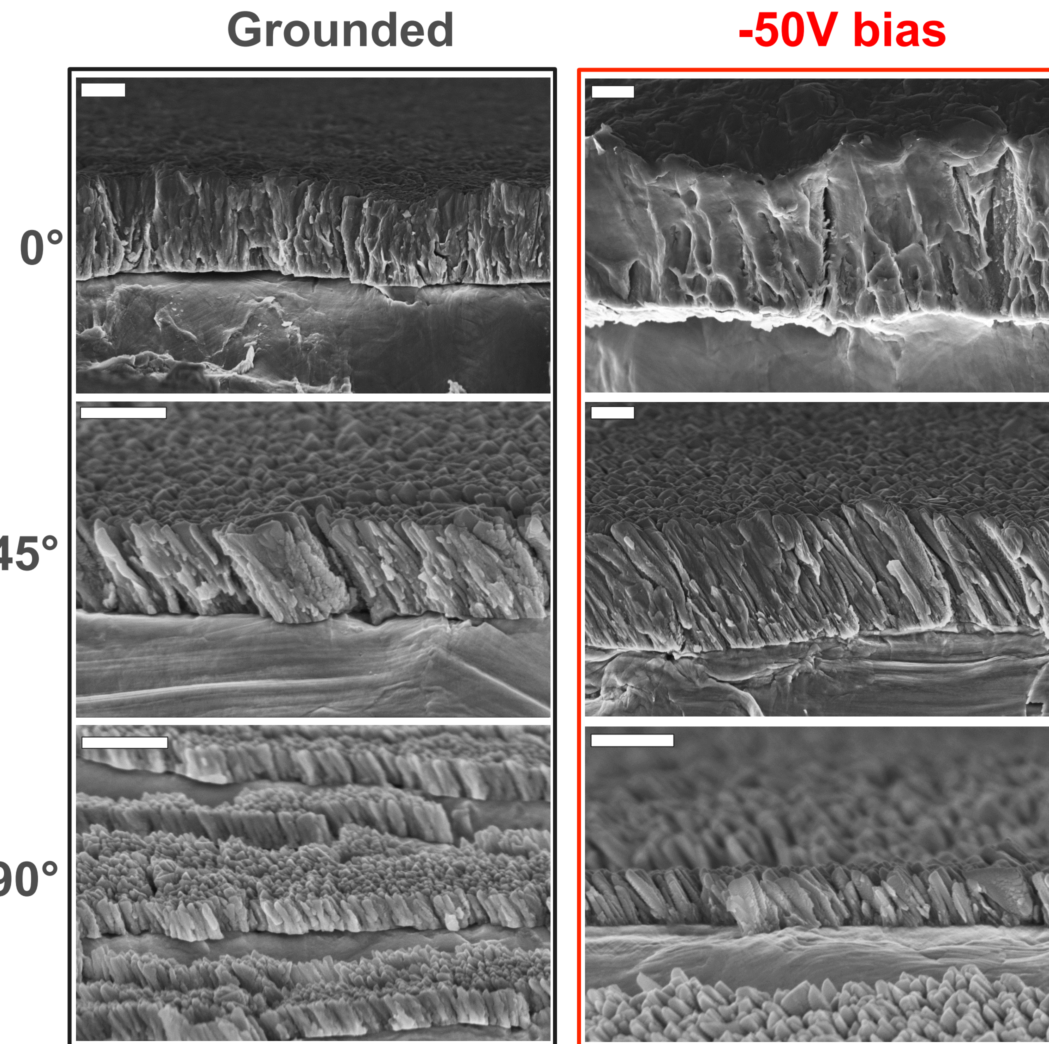
DCMS coatings
Not sensitive enough to bias → low ion flux

Unbalanced magnetron source could help to enhance the layer densification

ONLY if the ion flux is distributed all over the cavity surface

MC thin film growth simulations





Impinging angle effect - HiPIMS

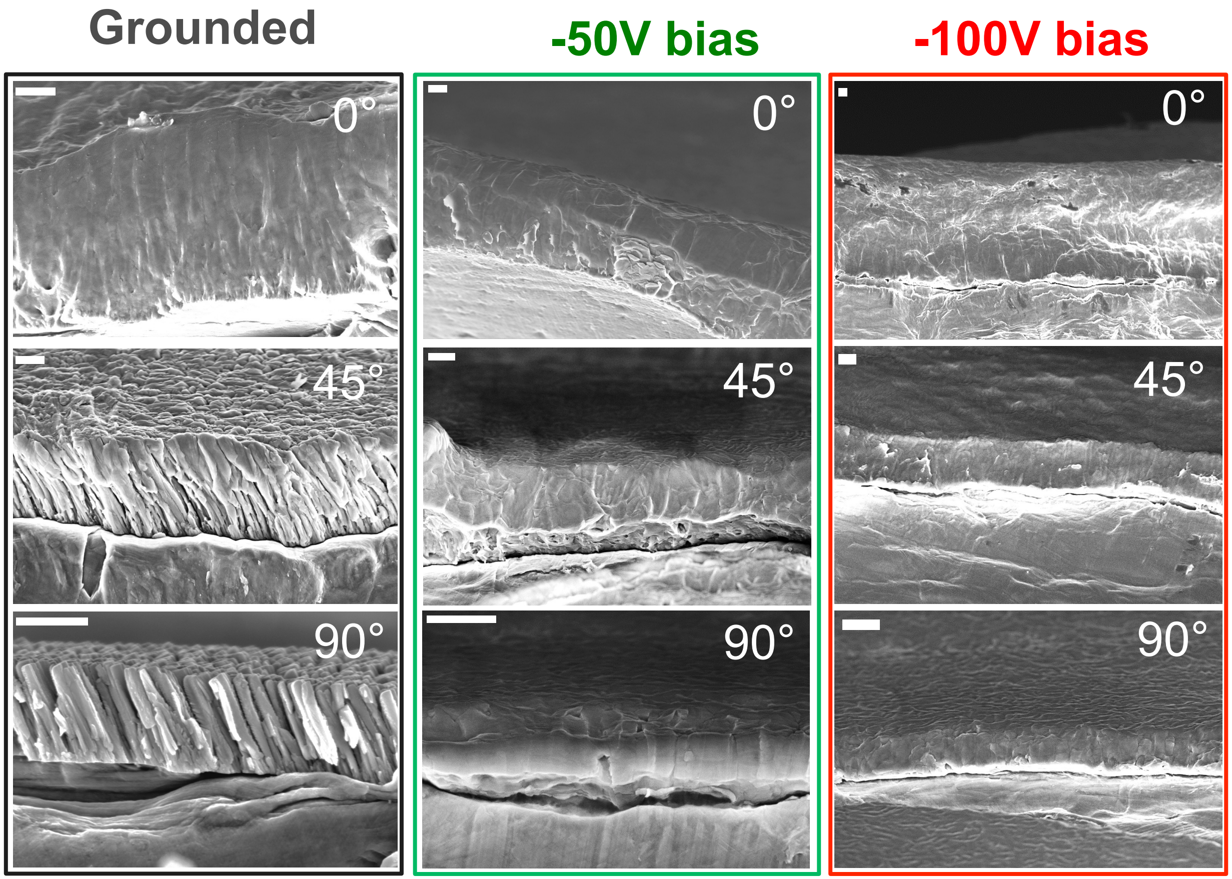
HiPIMS coatings

Grounded coatings similar to DCMS yet denser for normal incidence

Bias strongly densifies the layer no matter the sample orientation

Very promising for cavity performances

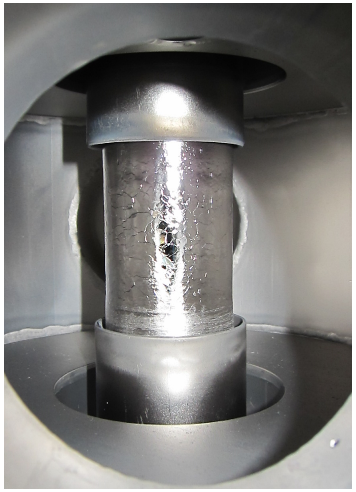
Porosity to be characterized by FIB-SEM



Progress

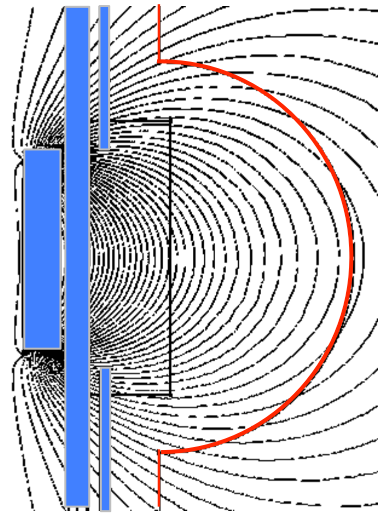
- Re-assessed the baseline after upgrade.
  - DCMS coating
- First HiPIMS+biased cavity coating (M2.10)
  - Surface preparation issue leading to peel-off in a cut-off
- 2nd coating done 4.07 → to be measured WW28
- Development of an unbalanced magnetron source
  - Increase ion flux density at the cavity surface

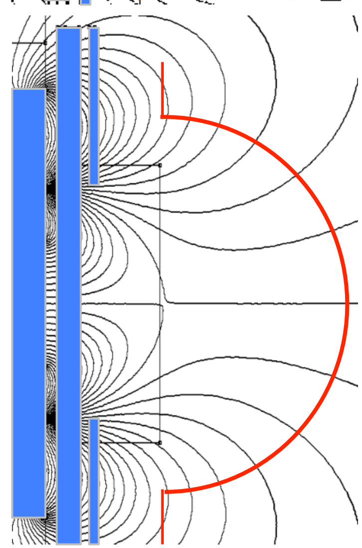
Unbalanced magnetron source

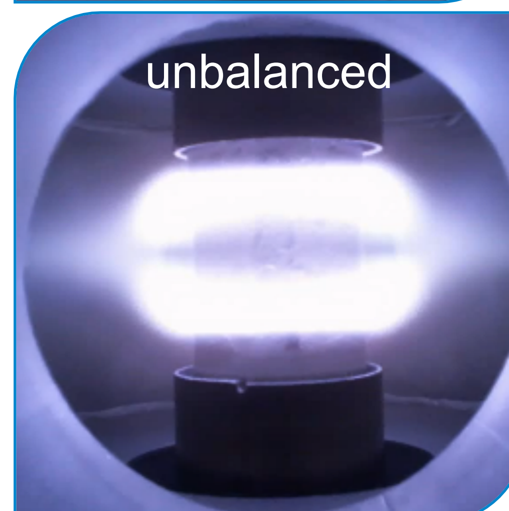


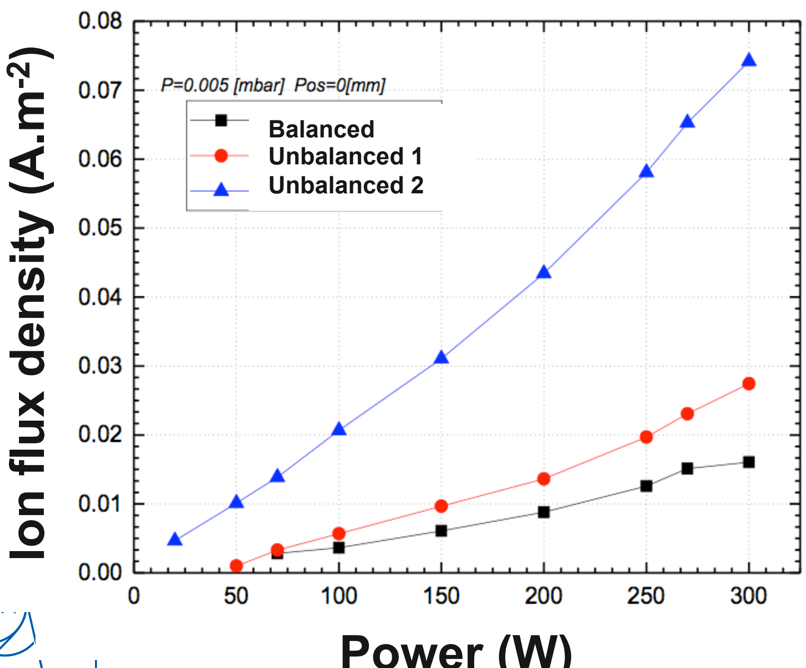
Standard magnet used (LHC etc…) → balanced source

Low ion flux at the surface: plasma electrons confined close to the target



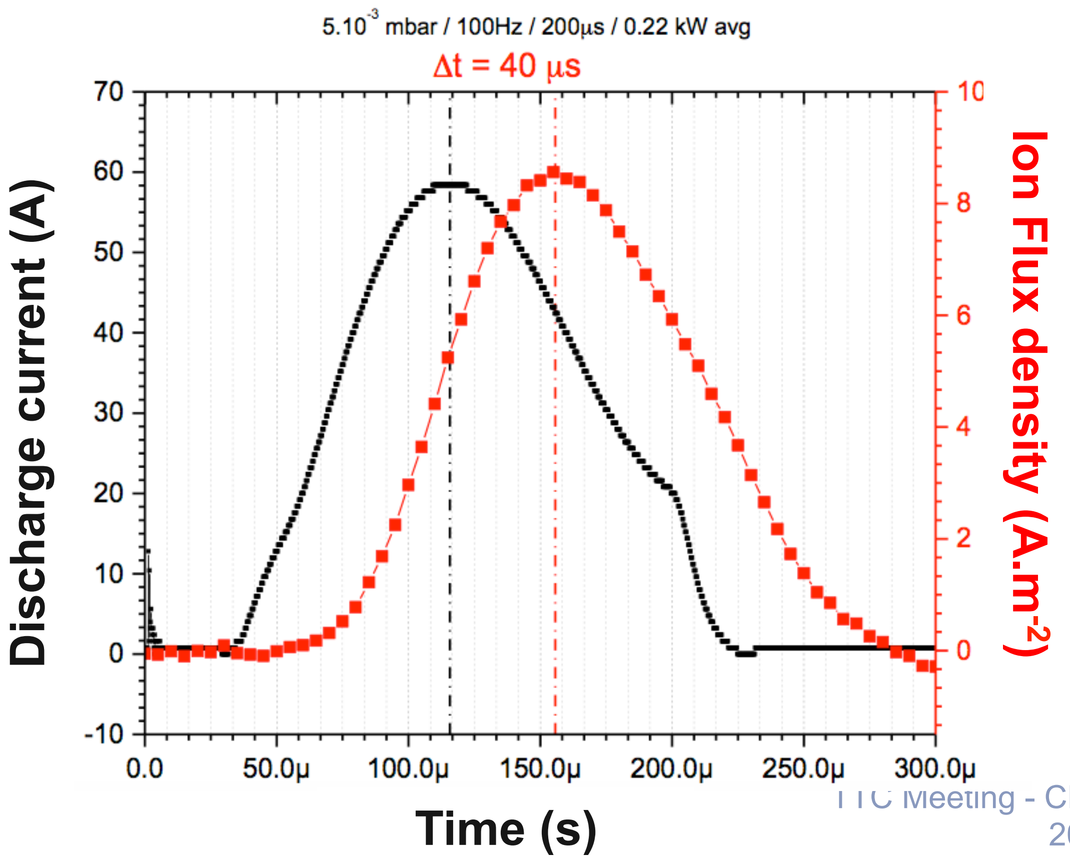






Unbalanced source for HiPIMS

- Characterization on going
- Promising first results
- Ion flux increased by 100 wrt DCMS



R&D activities

A15 Materials

Materials

- Nb_3Sn
- Composition sensitive
- Most promising from RF point of view
- Already proven capabilities (on bulk Nb) at Cornell

- V_3Si
- Cu contamination could be a killer
- Diffusion barrier layer compulsory

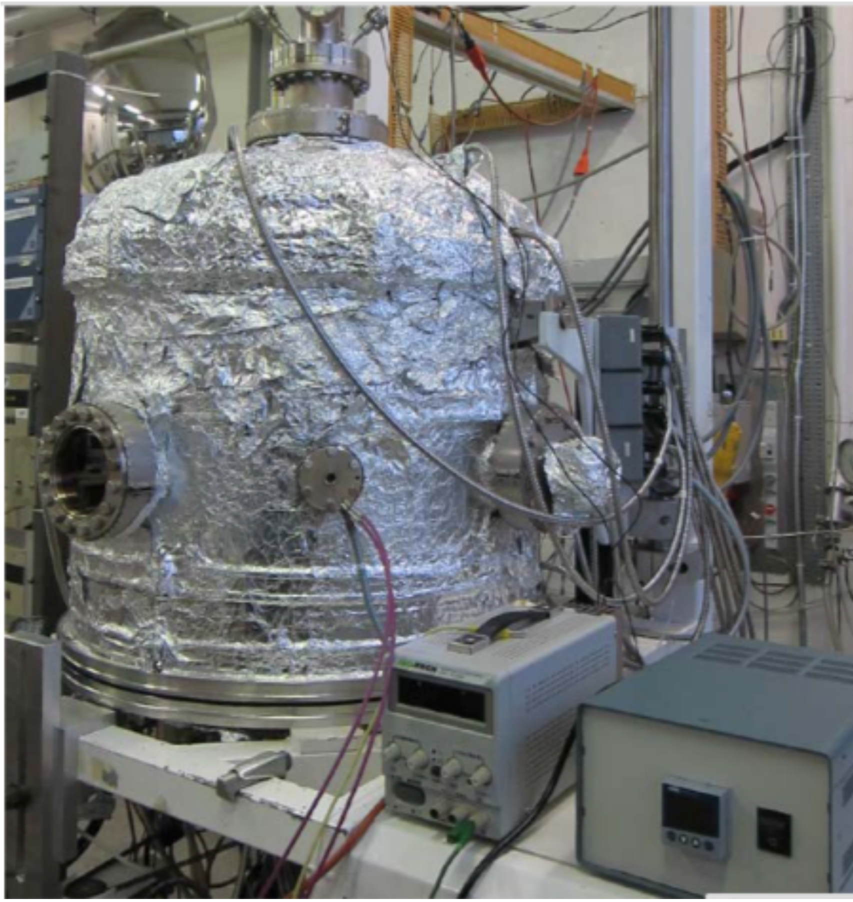
Stoichiometry control

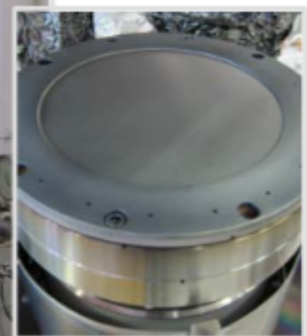
Thermal treatment → A15 phase

Annealing post coating or high temperature coatings

Mixed target at A15 stoichiometry value 3:1

Set-up





5.10-4 mbar < P < 5.10-2 mbar

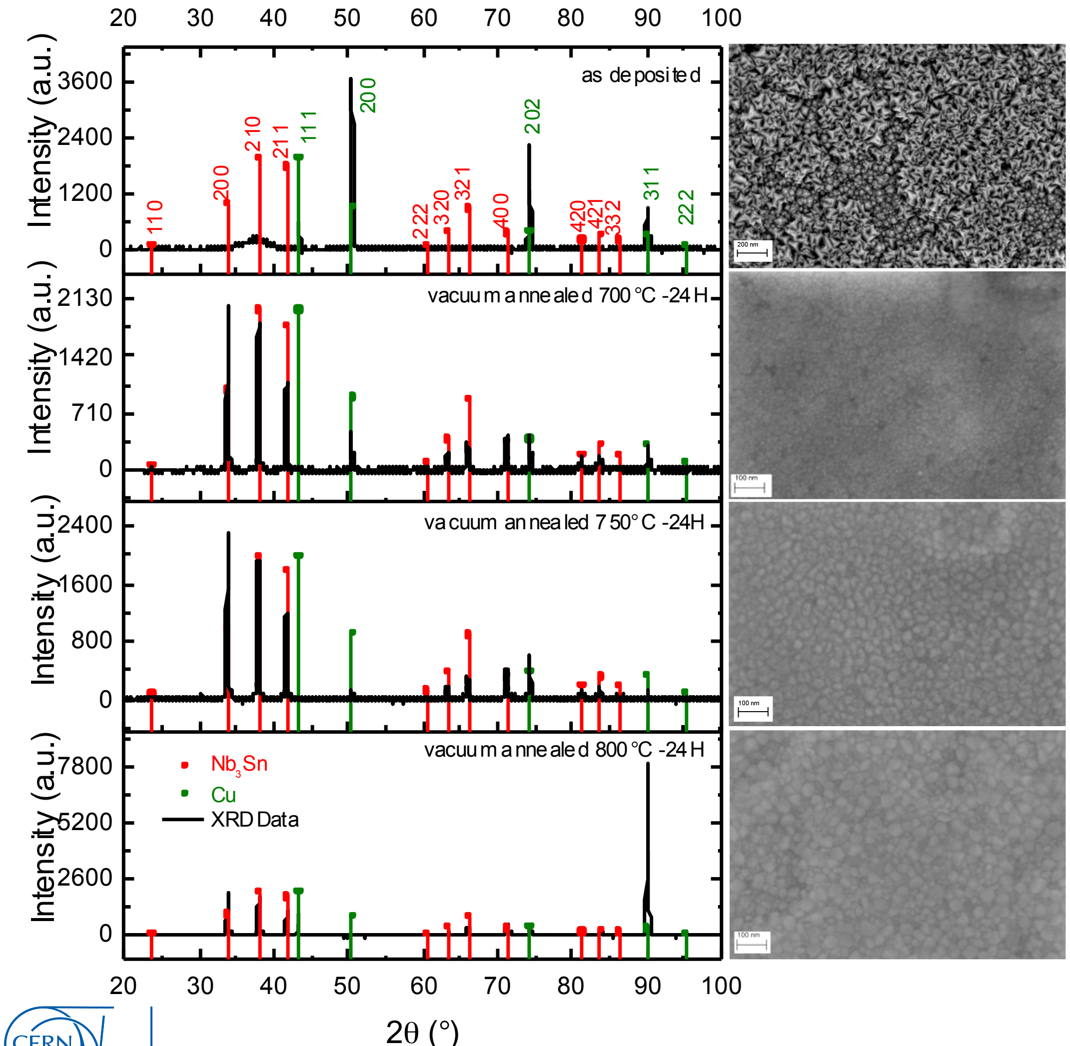
Kr / Ar

BO: 130°C

150 mm targets

In situ heating possible

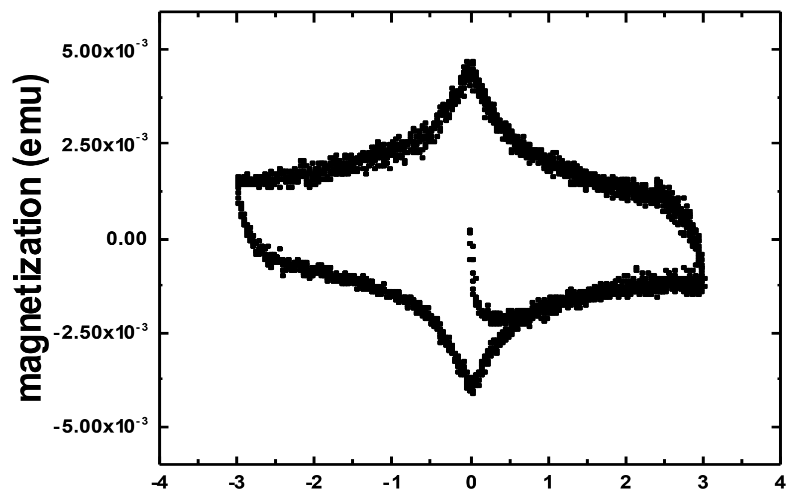
Nb_3Sn – Annealing post coating



As deposited layer: nanocrystal but mainly amorphous

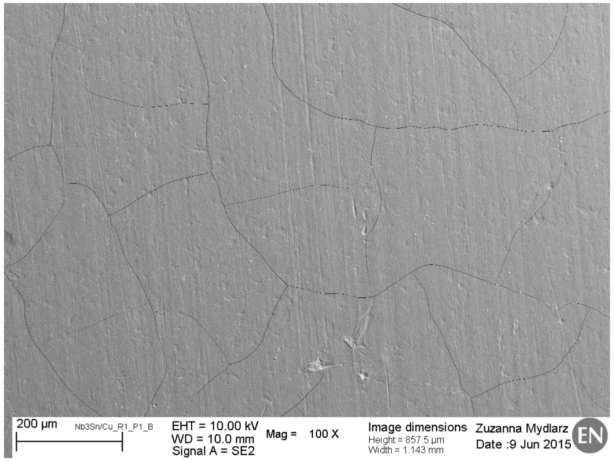
After annealing: A15 phase obtained even after annealing at low temperature.

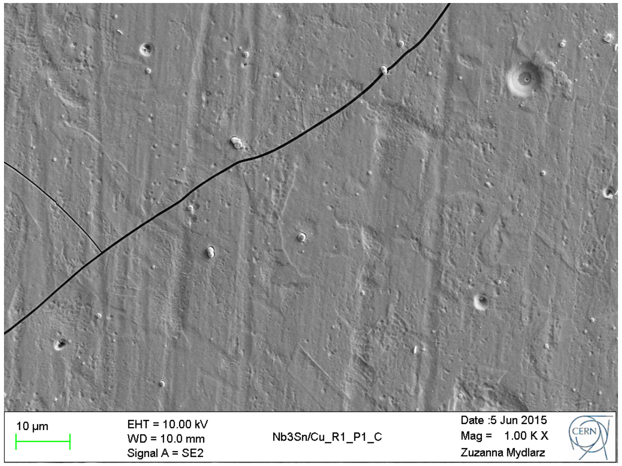
DC measures confirm the obtention of a superconducting phase
Strong hysteresis suggests flux pinning

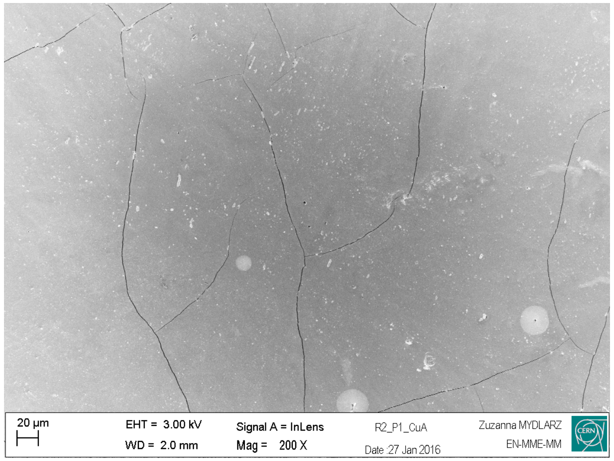


Nb_3Sn – Annealing post coating

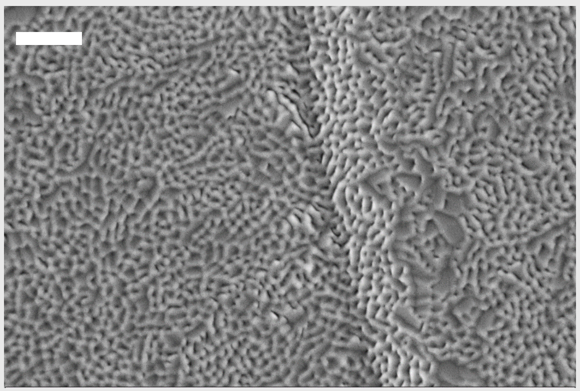
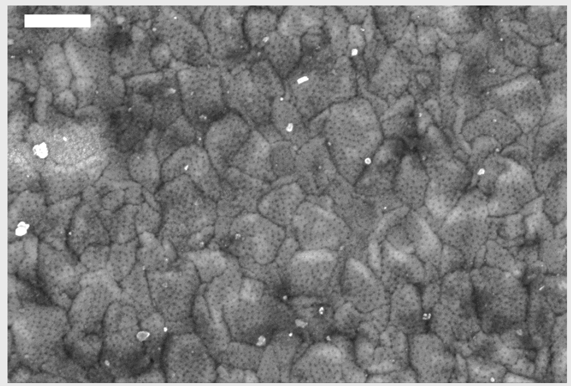
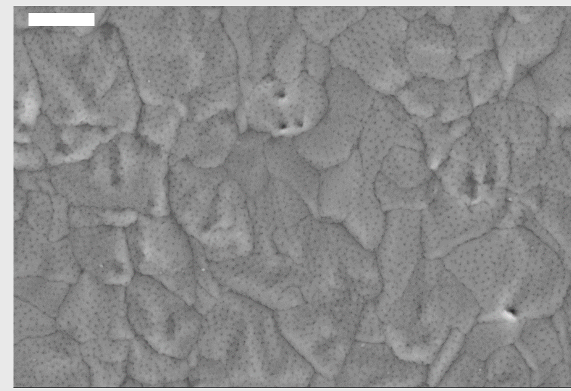
- Film cracking issue
- Not SRF compatible yet
- Work ongoing for stress mitigation
  - Buffer layer
  - Thickness optimization



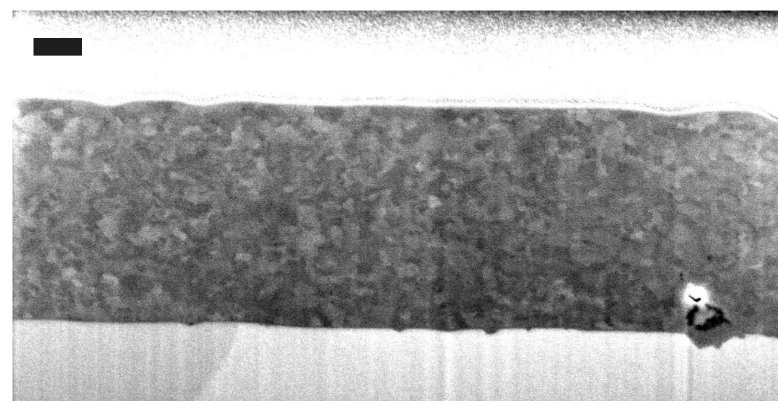




Nb_3Sn – High temperature coatings

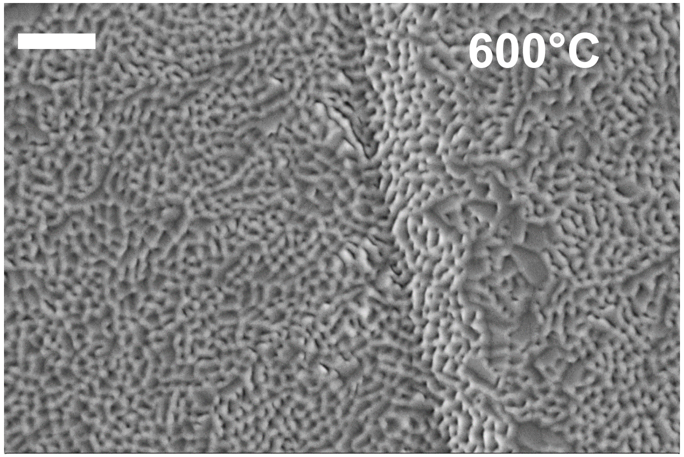
T=600°C	T=680°C	T=710°C
		

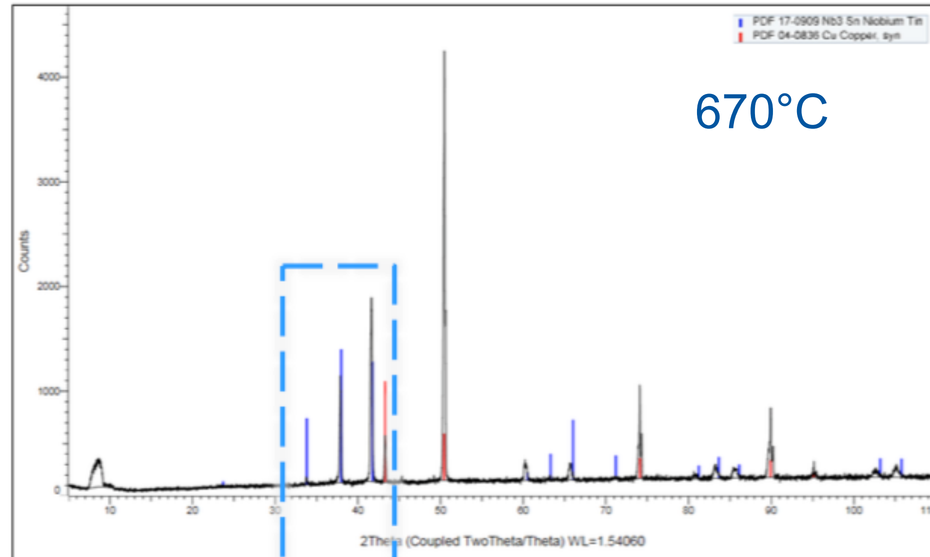
No film cracking
Dense layer
A15 phase obtained according to XRD
Isotropic grain structure

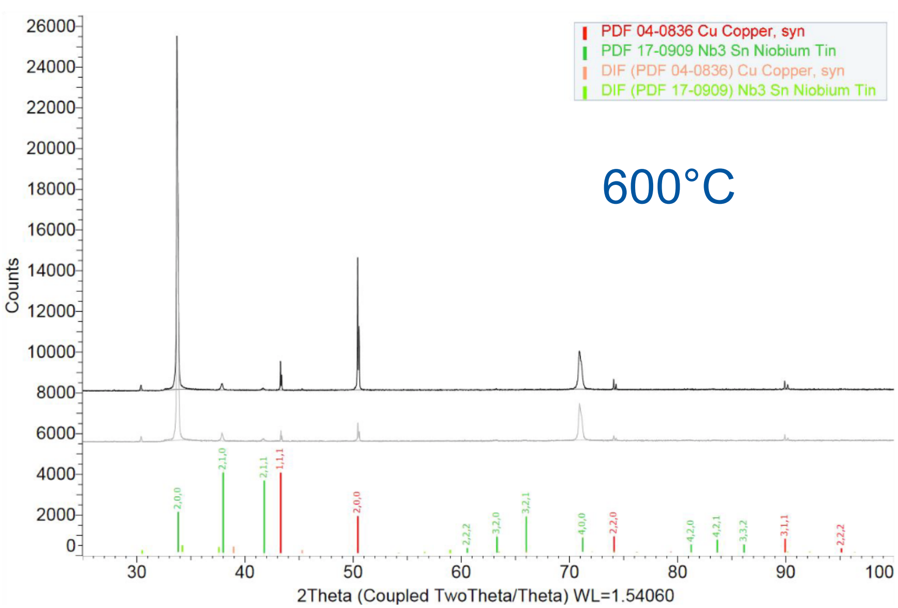


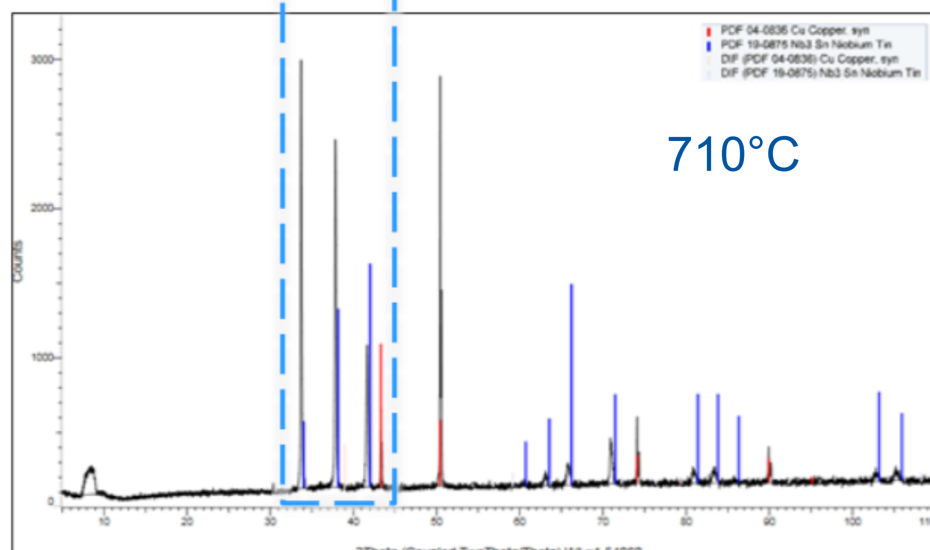
BEST CANDIDATES FOR RF TESTS

Nb_3Sn – High temperature coatings









Conclusion/perspectives

HiPIMS:

- Biased configuration looks very promising from a layer morphology point of view
- First HiPIMS + Bias cavity to be characterized WW28/29

A15:

- Nb_3Sn high temperature coatings give smooth and dense layers
- VSM/SQUID measures to be performed
- QPR coating to assess the RF performances of these films
- V_3Si: recipe development on-going

OPEN QUESTIONS

- Which coating parameters seem to have the biggest influence on the RF performance?
- Depends on the technique used.
    - HiPIMS:
        - peak power → coating rate (contamination), ionization level
        - Bias → film density, adhesion

- (When) will we get a Q-slope free cavity/what will it take? is there a unique cause for slope in films or many causes of different nature, varying form cavity to cavity?
- Thermal boundary resistances look like very good suspects. Energetic condensation (ECR, HiPIMS …) would be very suitable to adress this issue through surface engineering.