CERN

Nb/Cu studies at CERN

FCC week 2018, Amsterdam, 9-13 April 2018

G. Rosaz (CERN, TE/VSC)

On behalf of:

HIE-ISODLE working group

LHC spares cavity working group

FCC RF WP3 team

OUTLINE

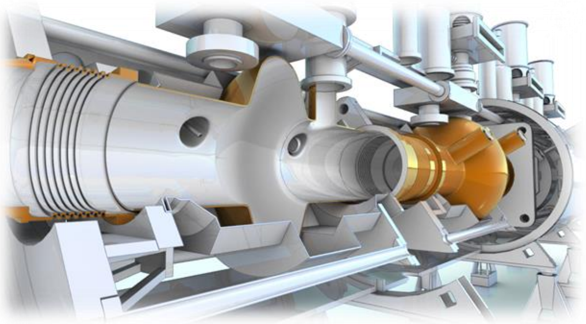
1. Current projects
   - HIE-ISOLDE
   - LHC spares program
   - Latest Results

2. On-going R&D
   - HiPIMS
   - A15

3. Future projects
   - WOW
   - FCC 400/800

4. Conclusion

1. Current Projects



1. HIE-ISOLDE Overview

Superconducting booster for ISOLDE radioactive ion beam facility at CERN

39 MV needed to reach 10 MeV/u

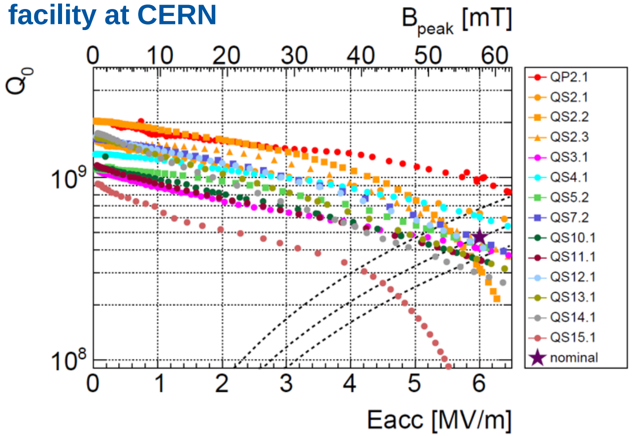
for A/q = 4.5 (highest possible at ISOLDE)

25 Quarter Wave Resonators cavities

→ cavities production for phase 2 completed,

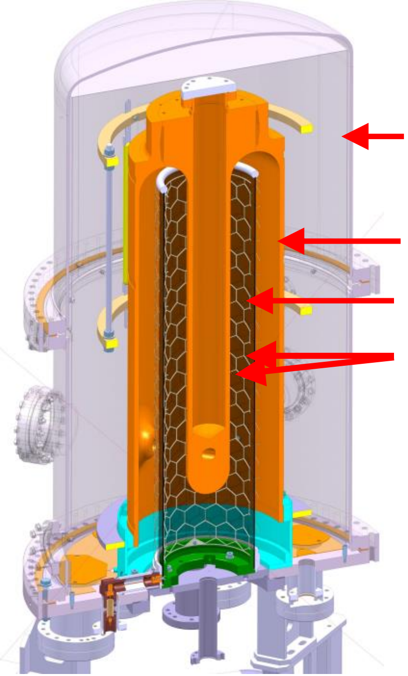
→ 4^{th} cryomodule under commissioning,

→ + 3 spare cavities produced out of 5



Frequency	101.28 MHz
Specification	6 MV/m @ $Q_0 = 4.7\times10^8$

HIE-ISOLDE Coating Setup



- **Cavity in UHV chamber**
  (10^{-8} mbar base vacuum)
- Cu cavity substrate, biased at -80 V
- Nb cylindrical cathode **used on both sides**, not cooled
- Anode grids on both sides of cathode, grounded

→ **DC-bias diode sputtering, 8 kW, 0.2 mbar Ar**

→ Cavity bake-out to 650°C (IR lamps) prior to coating

→ Coating at high temperature (300 → 620°C)

→ 15 runs of 25' each, net coating duration = 6h

→ Multi-layers due to coating run/cool-down cycles

→ Nb layer thickness ranging from 1.5 μm to 12 μm

LHC Spares - Overview

→ 8 Spare cavities to be manufactured, Nb coated and dressed with He-tank

Practice cavities (PC): 3 coatings

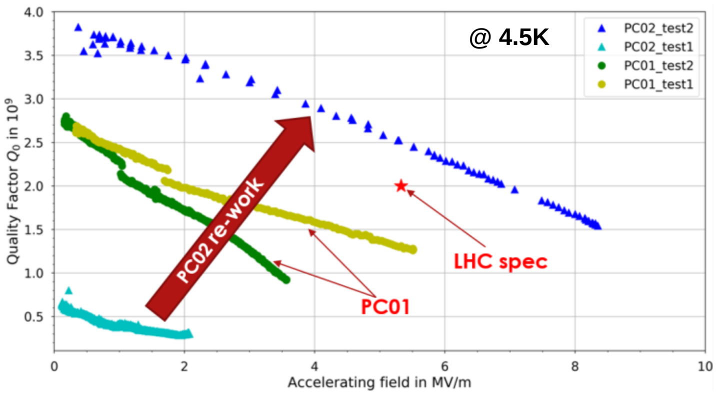
PC01 recoated: substrate structural defect

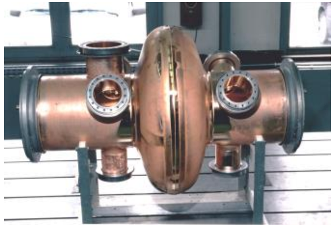
PC05: coated, RF test pending

PC02 recoated:

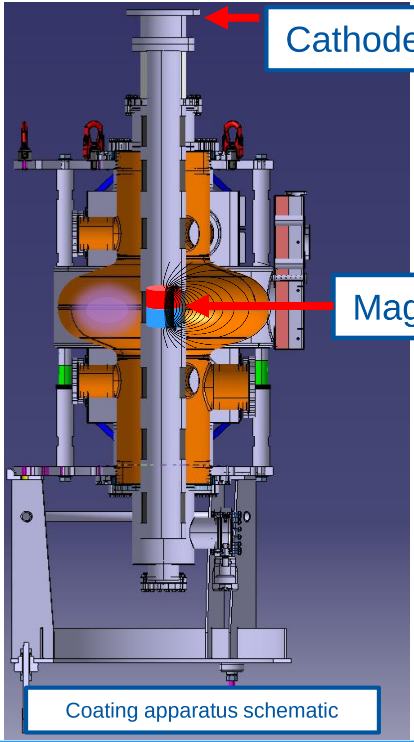
- Cavity at specs ($Q_0 = 2.2.10^9$ at 6 MV/m)
- Coating recipe and assembly flow validated
- Ability to recover a heavily damaged cavity by surface machining

Frequency	400.8 MHz
Specification	5 MV/m @ $Q_0 = 2x10^9$





1. LHC Spares – Coating Setup



Coating apparatus schematic

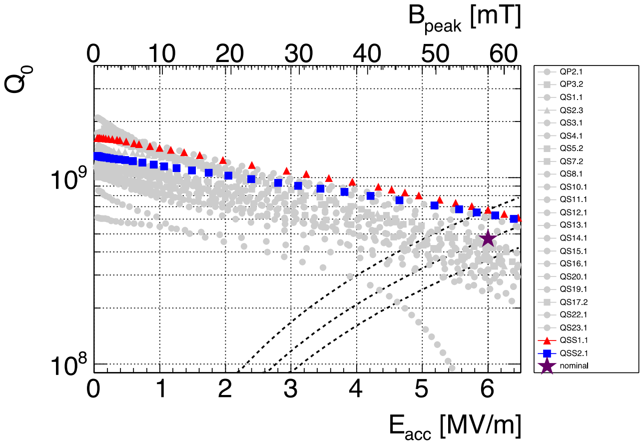
- **Cavity as UHV chamber**
  (10^{-10} mbar base vacuum)
- Cavity = anode, grounded
- Nb cylindrical cathodes tubes
- **movable electromagnet inside**, liquid cooled

→ **DC-magnetron sputtering, 6 kW, 1.10^{-3} mbar Kr**

→ Cavity bake-out (bake-out tent) to 180°C
→ Coating 7 steps for the 7 different electromagnet positions
→ Duration = 1h 20' at low temperature (150°C)
→ Nb layer thickness ~ 2 μm

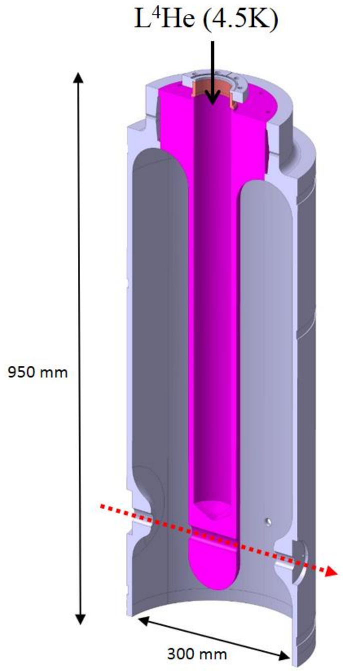
1. Latest Results

HIE-ISOLDE

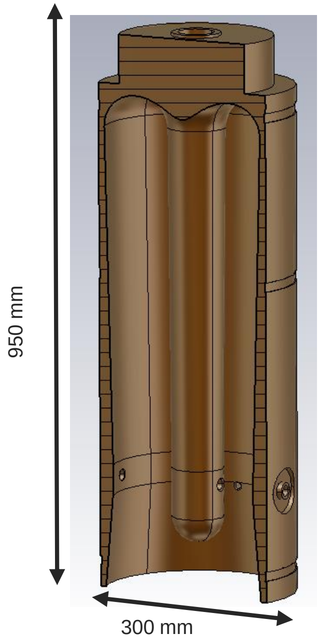


2 seamless cavities produced and coated
Best performances ever obtained

Original design



Seamless design



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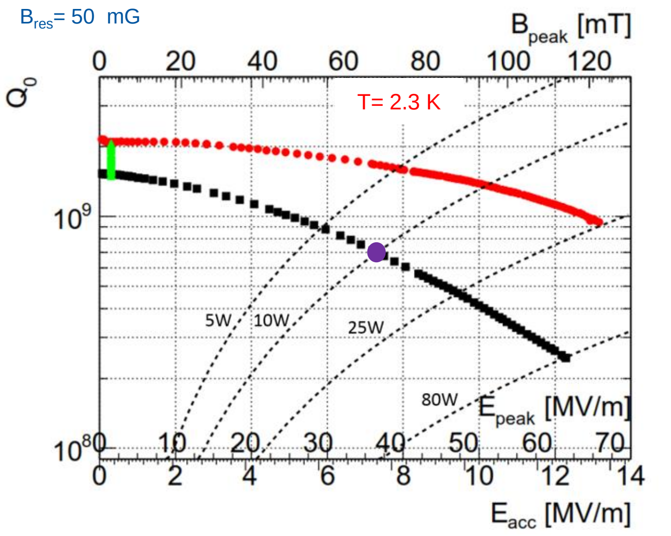
HIE-ISOLDE



Highest field ever reached by a Nb/Cu cavity

(~30MV/m in elliptical shape)

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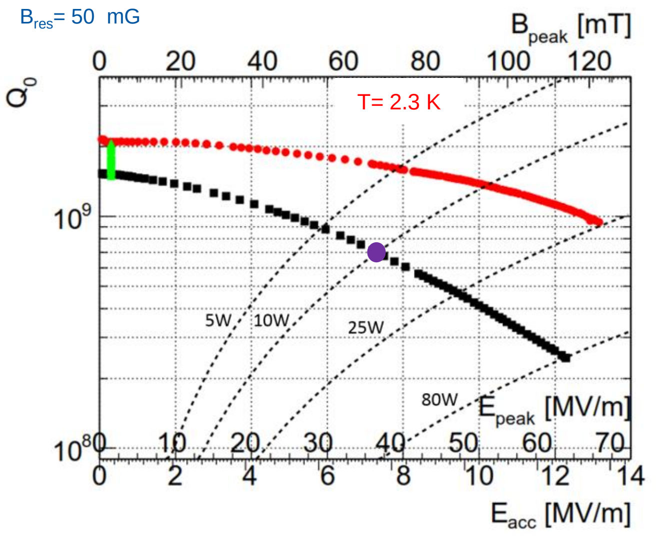
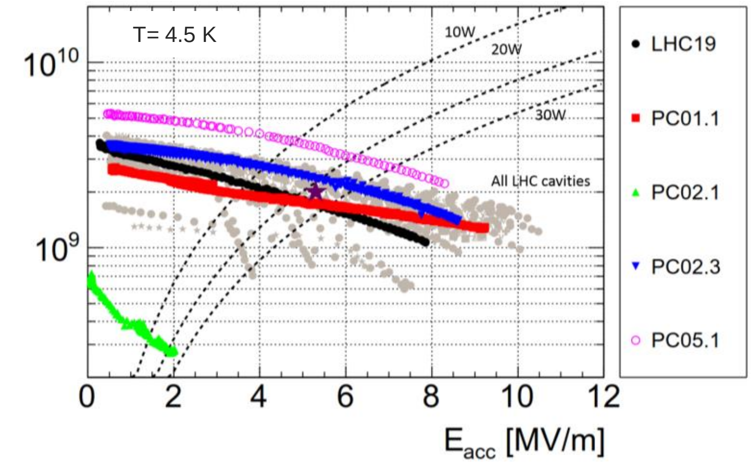


Highest field ever reached by a Nb/Cu cavity

LHC



PC05: (spun half cells) shows the **best performances among all LHC cavities ever produced**

Root cause not fully identified. Investigations on-going

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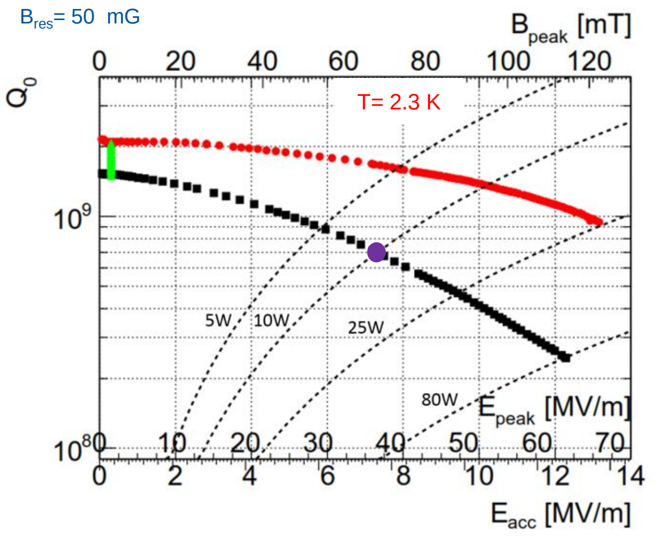
HIE-ISOLDE



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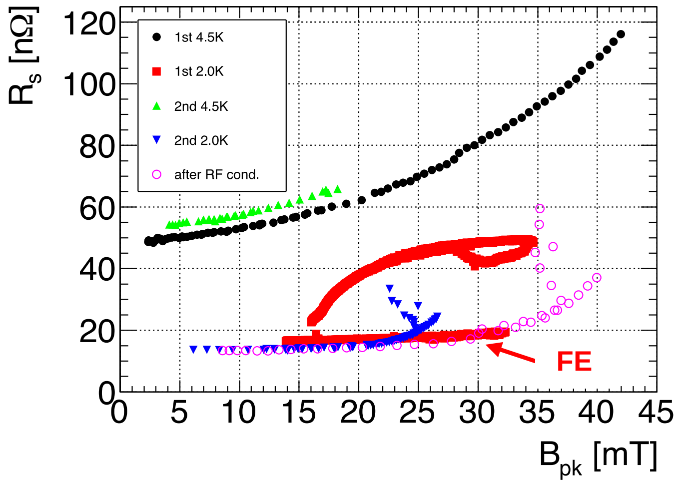
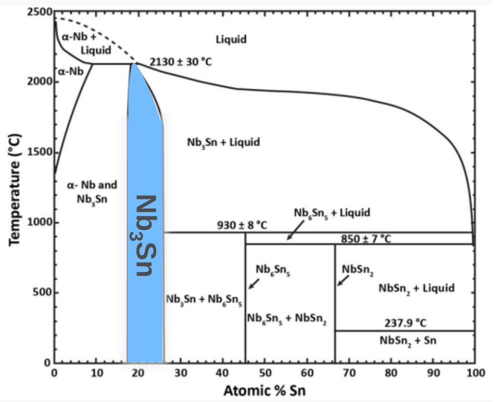


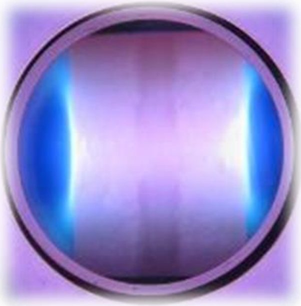
PC05: (spun half cells) shows the **best performances among all LHC cavities ever produced**

Rres ~ 15nOhms, FE limitation

Root cause not fully identified. Investigations on-going

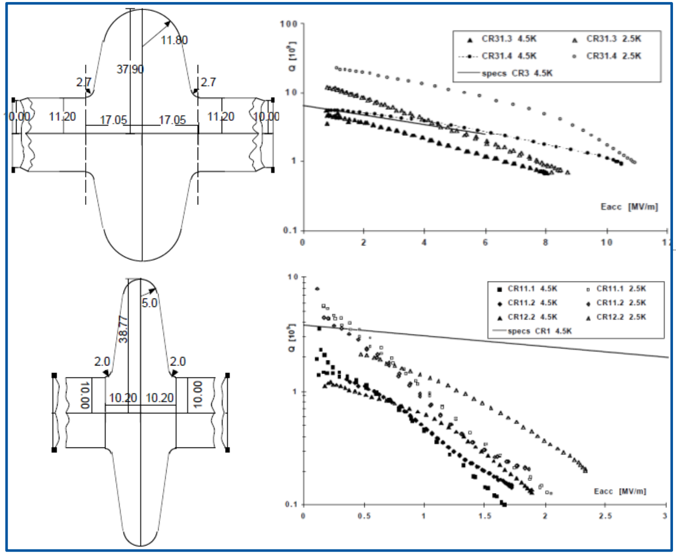

Liquid
α-Nb + Liquid
2130 ± 30 °C
α-Nb
Nb3Sn + Liquid
α- Nb and Nb3Sn
Nb3Sn
930 ± 8 °C
Nb6Sn5 + Liquid
850 ± 7 °C
Nb6Sn5
NbSn2
NbSn2 + Liquid
Nb3Sn + Nb6Sn5
Nb6Sn5 + NbSn2
237.9 °C
NbSn2 + Sn
Temperature (°C)
Atomic % Sn

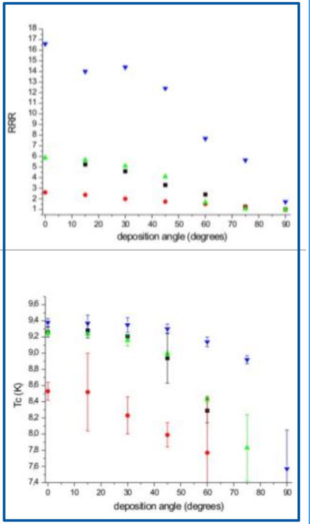
2. On-going R&D



2. HiPIMS

Problematic





[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

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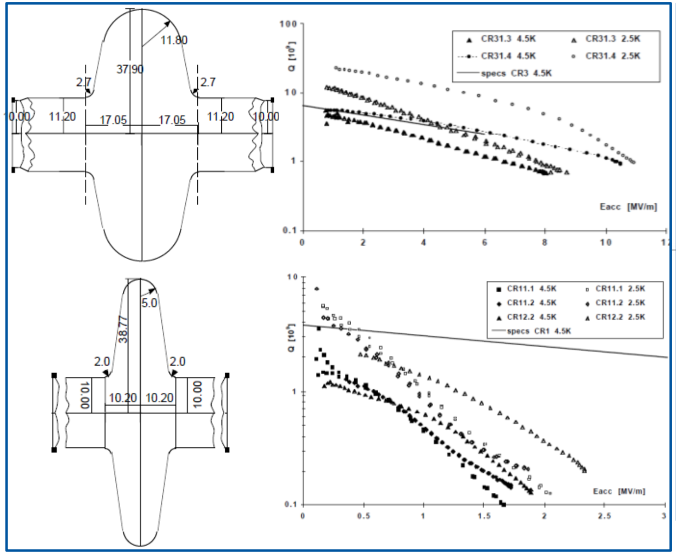

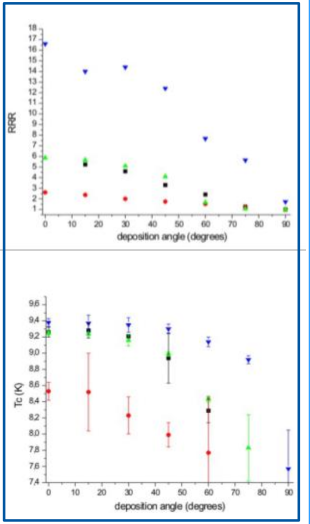

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Proposal

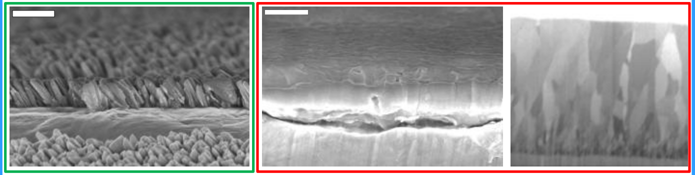
High **P**ower **I**mpulse **M**agnetron **S**puttering

- 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

Validation

DCMS (-50V bias) **HiPIMS (-50V bias)**

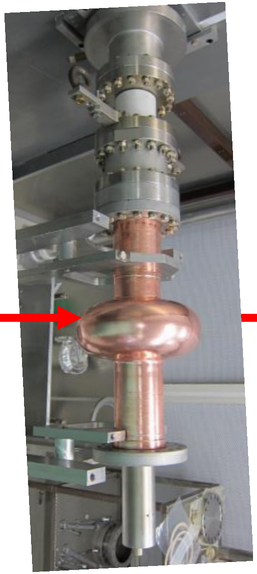


HiPIMS: Densification only if biased

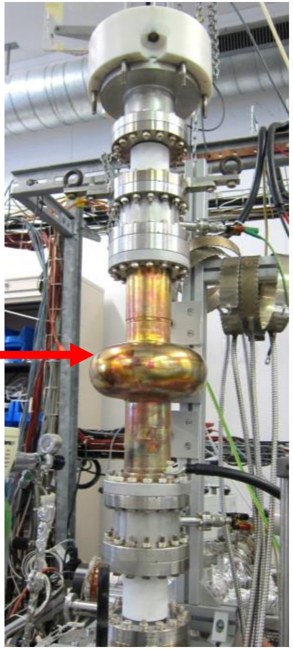
2. HiPIMS – Coating setup

- 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/week

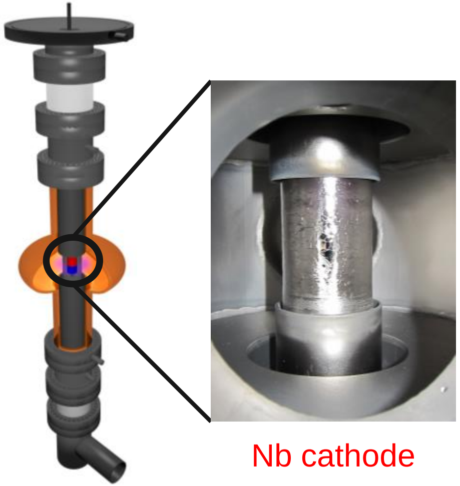
Nb cathode



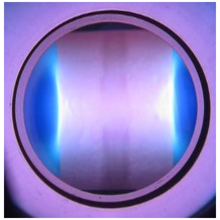
1.3 GHz cavity



1.3 GHz cavity coating setup

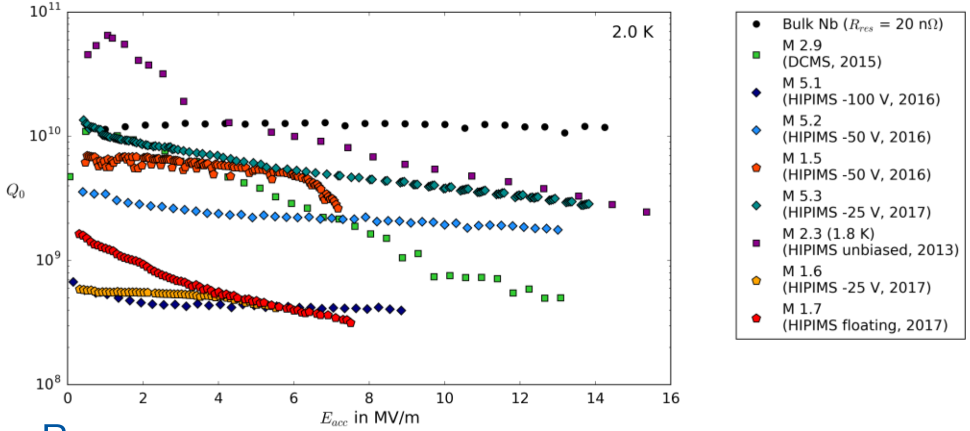


Nb cathode



HiPIMS discharge

2. HiPIMS – Results



Higher level of stress in HiPIMS wrt DCMS

→ Higher instantaneous coating rate

→ Peel-off is a recurrent issue

Stress
Surface defect
Local oxidation

R_{res}

- down to 5 nOhms with Q-slope (unbiased)
- 20nOhm with mitigated Q-slope (biased)

At the level of the best DCMS ones but not yet better

SUBSTRATE QUALITY IS CRITICAL

Study on going to qualify, quantify and mitigate residual stress

2. A15

Could we use another material than Nb?

Under investigation at Cornell, Fermilab

Nb_3Sn/Nb by Sn diffusion

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Could we use another material than Nb?

Under investigation at Cornell, Fermilab
Nb_3Sn/Nb by Sn diffusion

to coat a Cu cavity?

PLEASE STAY FOR

K.ILYINA (Material elaboration and properties)

M. ARZEO (SRF characterization)

A. LUNT (Microscopic analysis)

K. Ilyina-Brunner, magnetron sputtering of Nb3Sn thin films on copper for SRF applications, 11:06 - 11:24, P4 Berlage zaal, 1.9
https://indico.cern.ch/event/656491/contributions/2918336/

M. Arzeo, Quadrupole resonators characterization, 14:10 - 14:30, P4 Berlage zaal, 1.9
https://indico.cern.ch/event/656491/contributions/2932254/

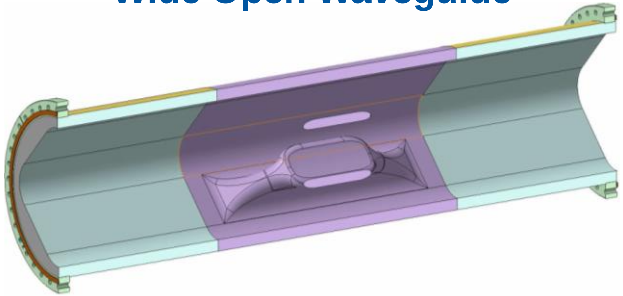
A. Lunt, Mirco-to-nanoscale characterisation of SRF coatings for the FCC using advanced FIB microscopy, 13:50 - 14:10, P4 Berlage zaal, 1.9
https://indico.cern.ch/event/656491/contributions/2915672/

3. Future Projects

3. WOW and FCC cavities

Nb/Cu crab cavity

Wide Open Waveguide



Coating feasibility under study by A. Sublet and F. Avino (CERN, TE/VSC)

1st coating in a real cavity forecasted for 2019

Alexej Grudiev , 15:50 – 16:10, P4 Berlage zaal (1.9) Innovative crab cavity design for FCC hh
https://indico.cern.ch/event/656491/contributions/2932264/

3. WOW and FCC cavities

Nb/Cu crab cavity

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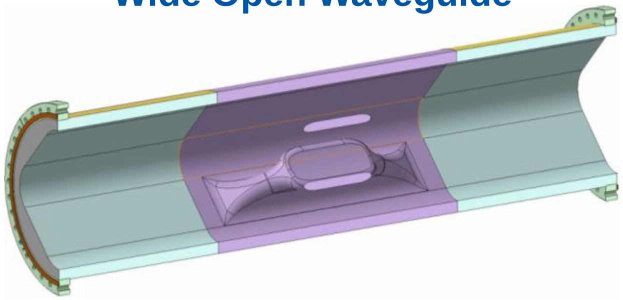

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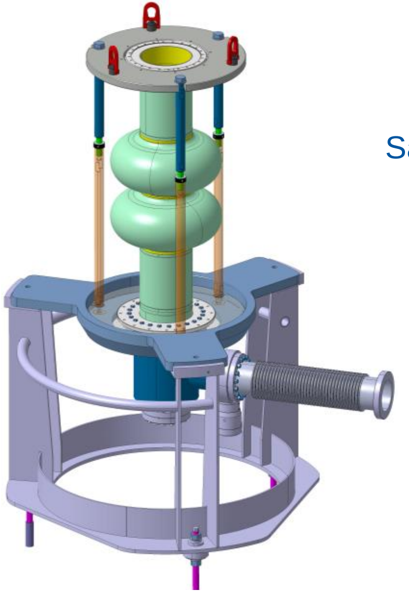
FCC cavities (400 & 800MHz)



Integration of a 800MHz double cell cavity on LHC coating bench

Same coating hardware as for LHC cavities

Identical for 400MHz
Upgraded for 800MHz

HiPIMS?
(Q-slope mitigation)

Spun seamless cavities
(Q_0 increase)

Conclusion

- HIE-ISOLDE and LHC cavities have shown exceptional performances

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- HIE-ISOLDE and LHC cavities have shown exceptional performances
- HiPIMS looks like a viable alternative to standard coating (DCMS) technique… still to be improved
- A15/Cu enter the SRF characterization loop… modest starting point but exciting perspectives
- Stimulating projects (WOW, FCC…) motivate for efforts on thin film R&D for SRF application

Thank you for your attention