Cristian **Pira**

On behalf of INFN LNL SRF group

New Technologies in Superconducting RF

FUTURE CIRCULAR COLLIDER

First FCC-Italy Workshop

Rome, March 21, 2022

i.FAST and EASITRAIN has received funding from the European Union's Horizon 2020 programme under GA No 101004730. and under GA no. 764879

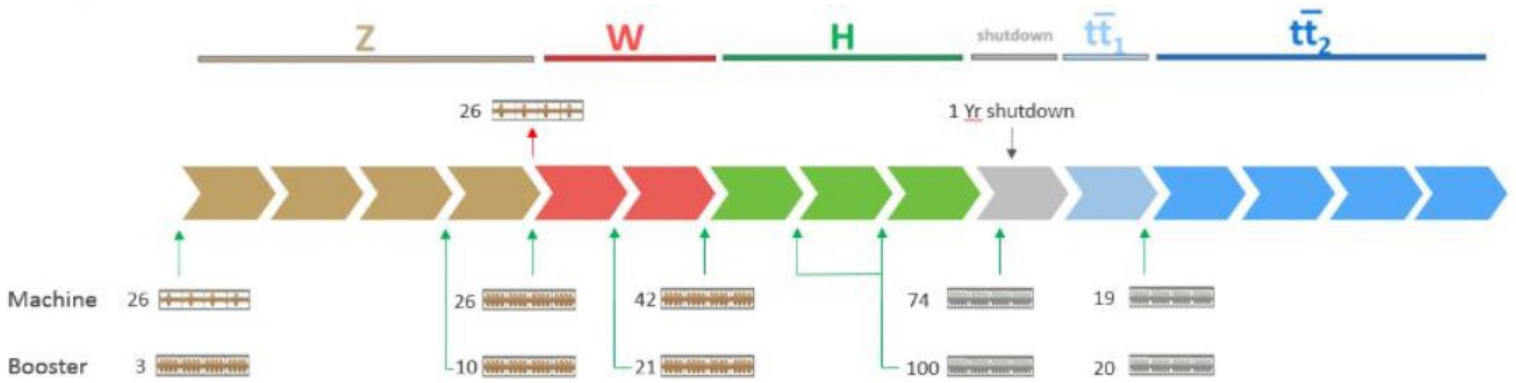
Outline

State of the art for FCC SRF cavities

R&D on substrate preparation

R&D on SC coatings

FCC SRF cavities choice



O. Brunner et al., FCC Week 2021

The machine will strongly change configuration during its lifetime

FCC SRF cavities choice

High Current Machine

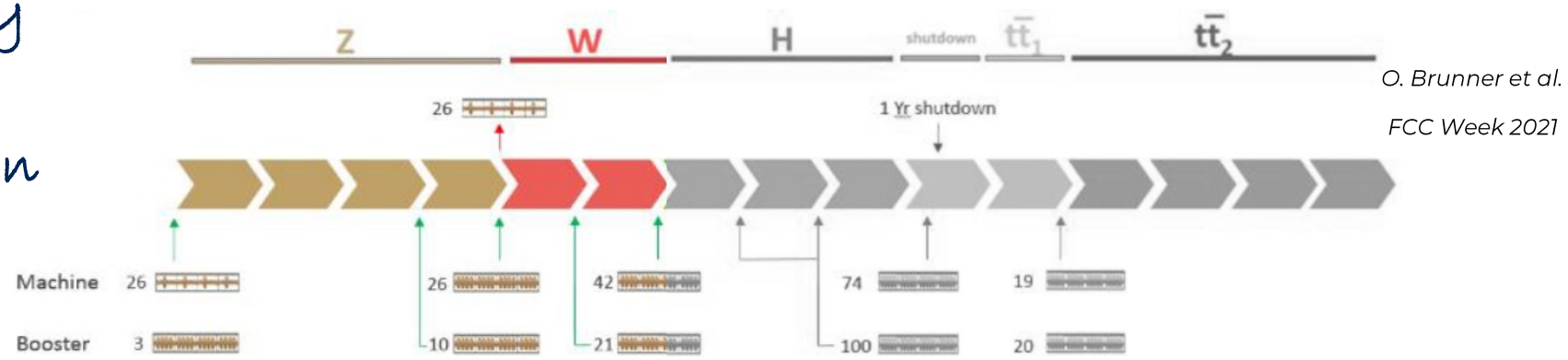
WP	V_{rf} [GV]	#bunches	I_{beam} [mA]
Z	0.1	16640	1390
W	0.44	2000	147
H	2.0	393	29
ttbar	10.9	48	5.4

Low frequency cavities

4.5 K operation

400 MHz

Nb thin films



O. Brunner et al.

FCC Week 2021

1 cell

104 cavities

E_{acc} = 5 MV/m

1 MW/cav

4cav./cryom

Re-used for FCC-hh.

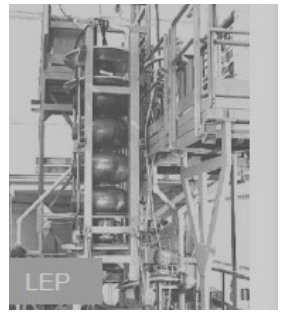
4 cell

408 cavities

E_{acc} = 10 MV/m

1 MW to 200 kW/cav

4cav./cryom



FCC SRF cavities choice

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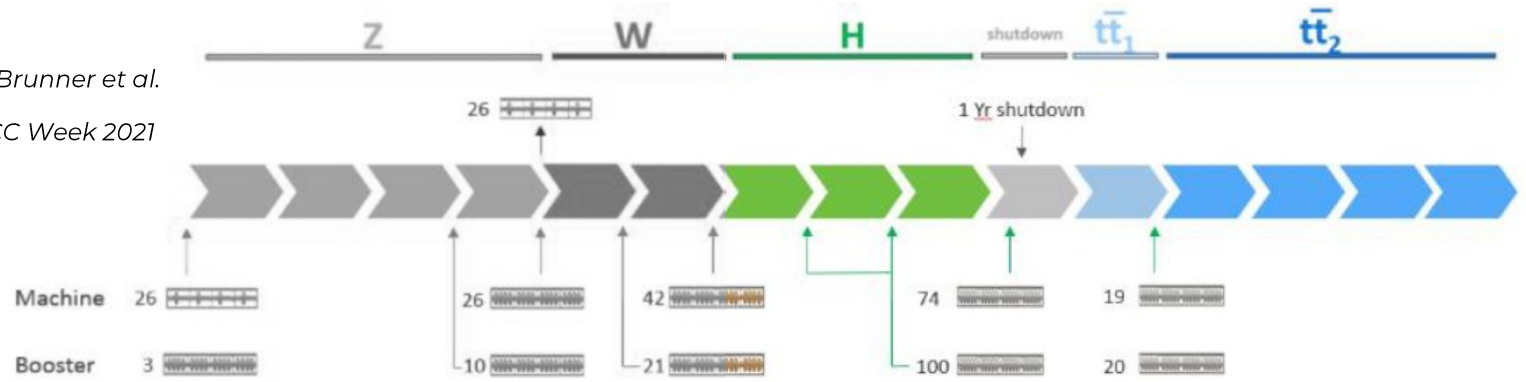
High gradient Machine

O. Brunner et al.

FCC Week 2021



High gradient cavities

2K operation

800 MHz

Nb bulk

5 cell

852 cavities

E_{acc} = 20 MV/m

200 kW/cav

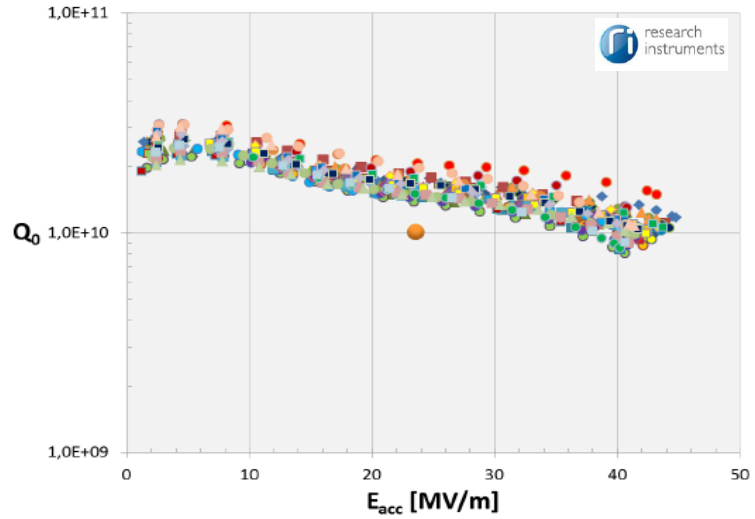
4cav./cryom.

Nb bulk state of the art

European XFEL

768 Nb bulk TESLA type elliptical 1.3 GHz cavity

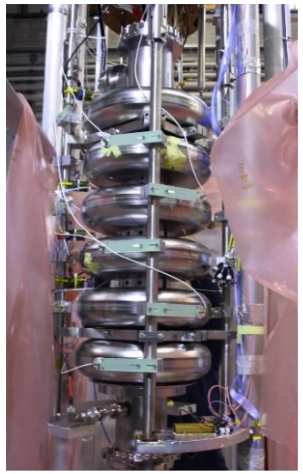
Accelerating Gradient closer to Nb theoretical limits

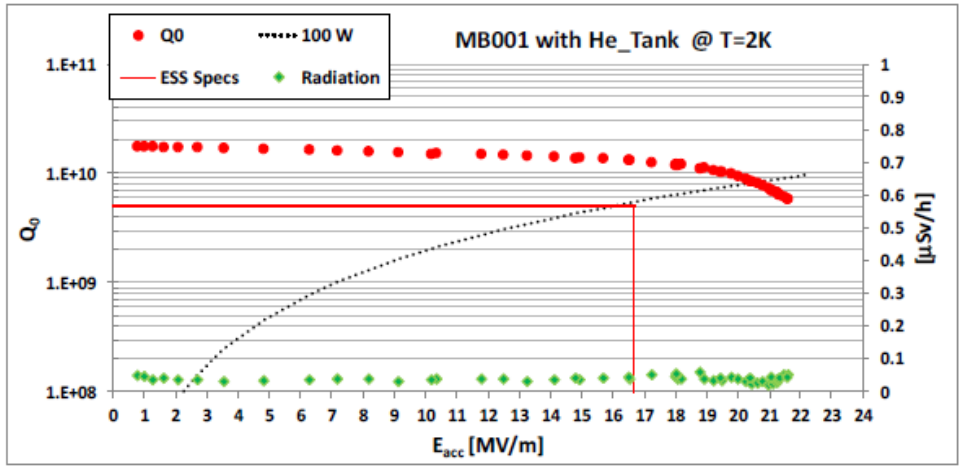


Technology already transferred at lower frequency (650 MHZ)

Performances closer to FCC requirement

ESS EUROPEAN SPALLATION SOURCE





D. Sertore, Proceedings SRF 2017

Nb bulk state of the art

European XFEL

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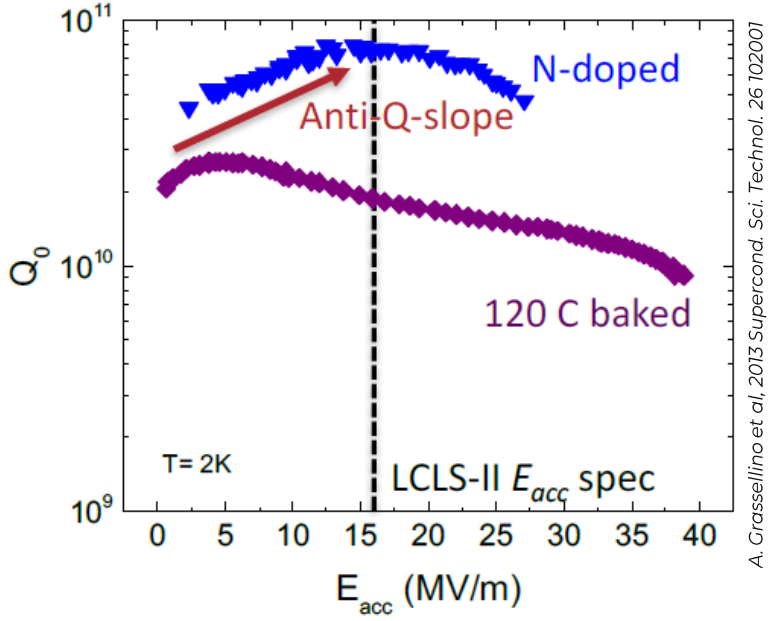


A. Grassellino et al, 2013 Supercond. Sci. Technol. 26 102001

Technology already transferred at lower frequency (650 MHZ)

Performances closer to FCC requirement

ESS EUROPEAN SPALLATION SOURCE

Room for Quality factor improvement

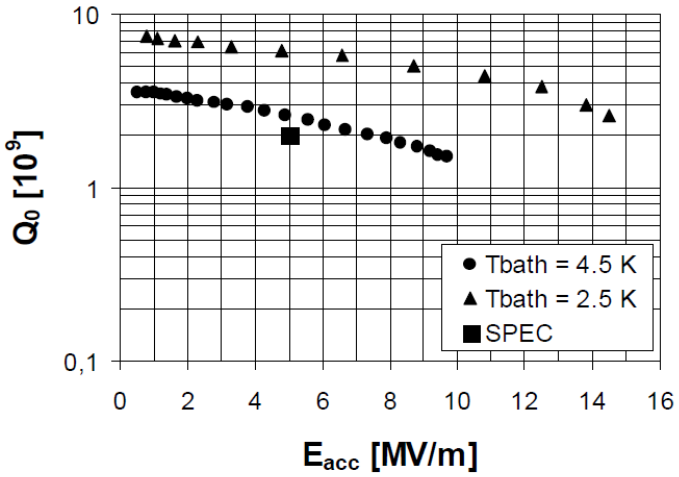
Nitrogen Doping technology

Some drawbacks to take in account:

- Less effective at 800 MHz
- High sensitivity to flux trapping

Nb on Cu state of the art

LHC



S. Bauer *et al.*, "Production of Nb/Cu sputtered superconducting cavities for LHC," 1999

21 elliptical 400 MHz cavities

produced by industry (ACCEL)

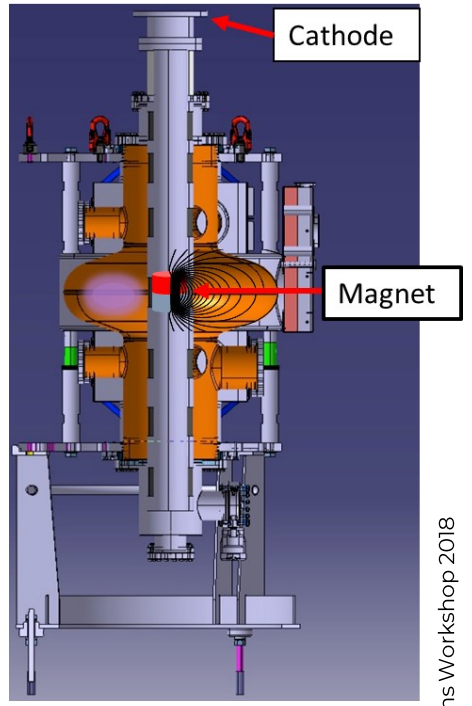
DC magnetron Sputtering Technology

Advantages:

Cheaper
Cu almost 100 times cheaper than Nb

4.5 K operation
Better thermal properties, low BCS resistance

Simpler cryostat design
No magnetic screening necessary



LHC cavity coating setup

A. Sublet, Thinfilms Workshop 2018

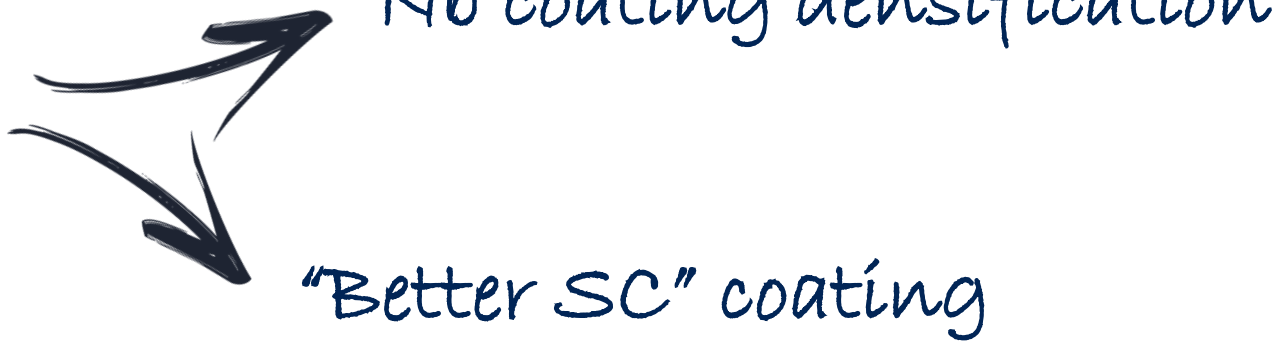
Still room for improvements

(Q-slope at high gradients)

Nb on Cu R&D

Cu substrate plays a fundamental role in SRF performances

Sputtering technology offers a wide range of optimization



Nb on Cu R&D

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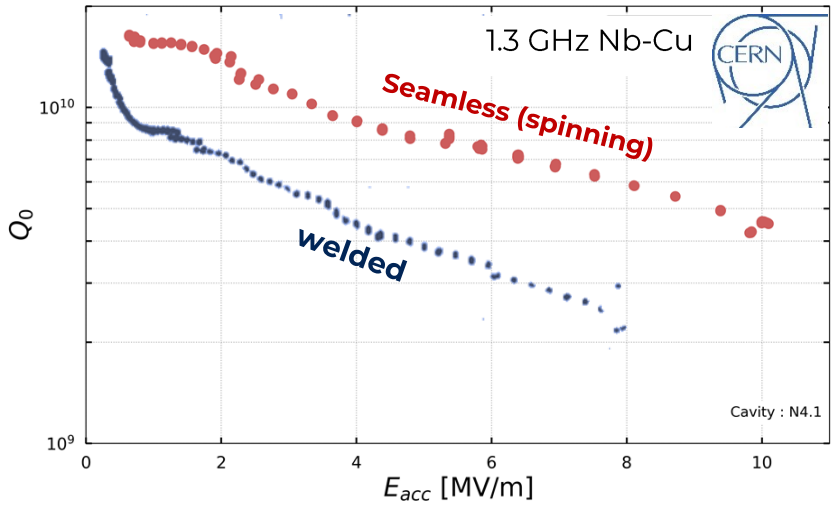


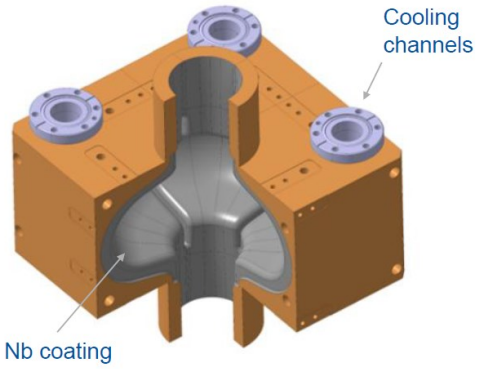
L. Vega Cid, TTC meeting 2022 (elaborated)

Cavity fabrication

Different possibilities:

Welding/seamless

Spinning, hydroforming, electroforming…



SWEEL cavity

Simpler coating procedure

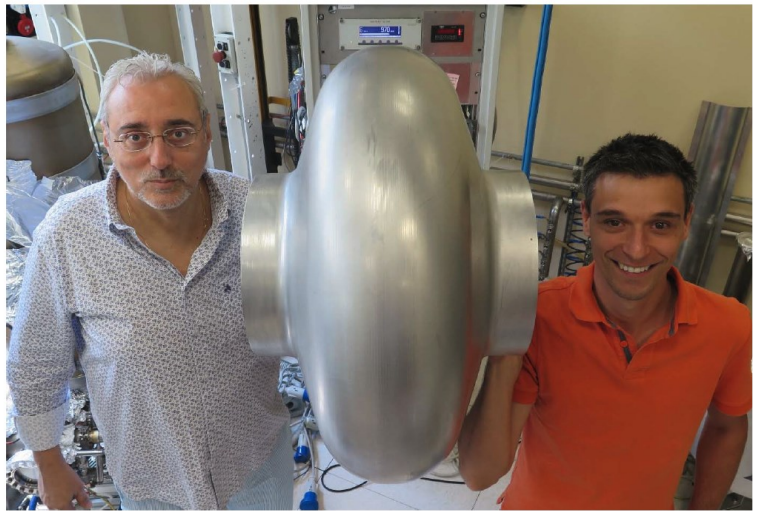
Different proofs of **seamless** RF performances **superiority**

(Hie-ISOLDE, ALPI-INFN, CERN studies, …)

Seamless Cavity Fabrication @LNL

Forming via spinning of seamless 400 MHz accelerating cavities

2015-2019 Collaboration Agreement KE2722/BE/FCC



First Aluminum Prototype by Enzo Palmieri

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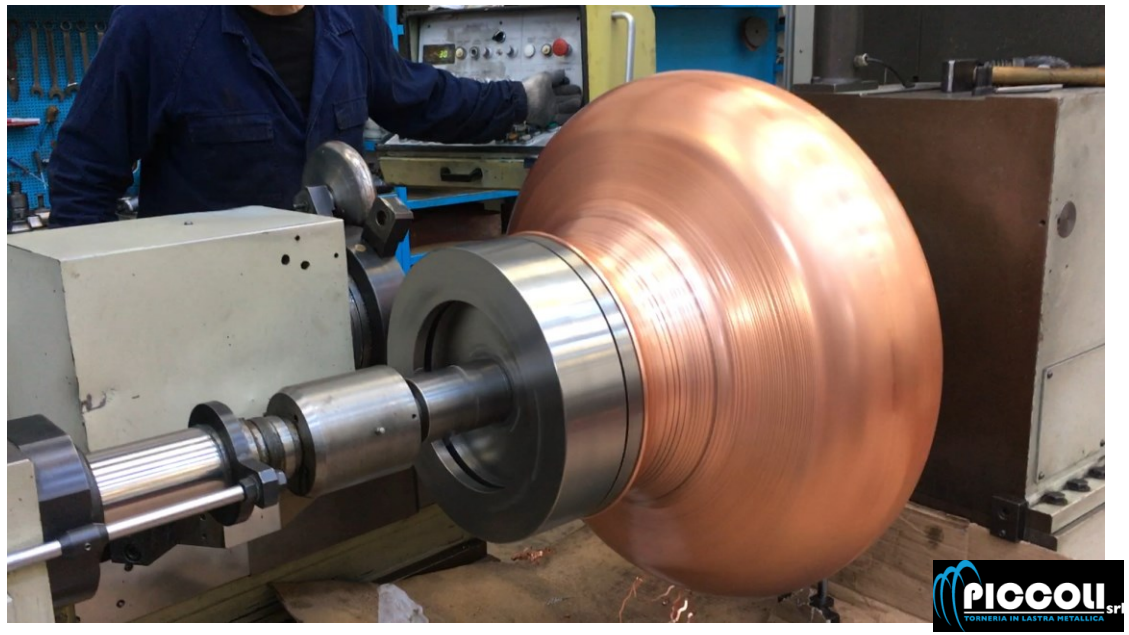

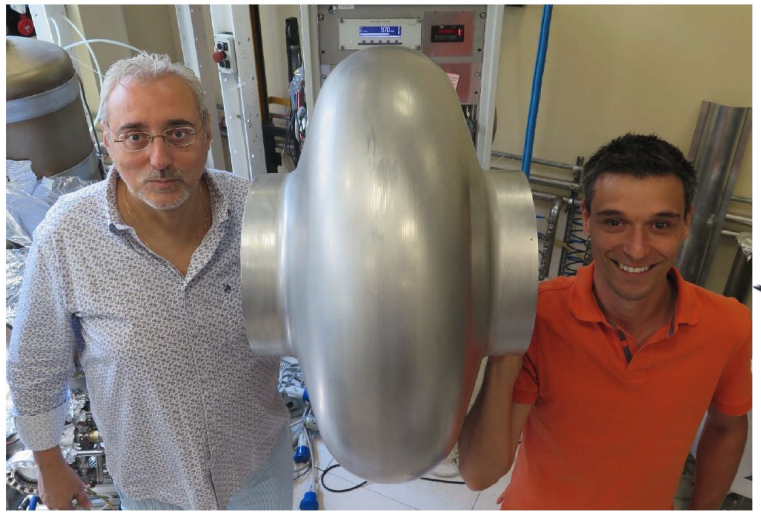

First Aluminum Prototype by Enzo Palmieri

Two Copper 400 MHz **seamless Prototype** realized

Seamless Cavity Fabrication @LNL

Forming via spinning of seamless 400 MHz accelerating cavities

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Azzolini et al, SRF2019 proceedings

3 intermediate annealings solve large cracks issue

Deep circunferential cracks on the iris

Two Copper 400 MHz **seamless Prototype** realized

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Azzolini et al, SRF2019 proceedings

3 intermediate annealings solve large cracks issue

Deep circunferential cracks on the iris

Further developments are necessary to:

- Increase iris thickness to prevent cracks
- increase geometry accuracy
- Increase internal surface quality

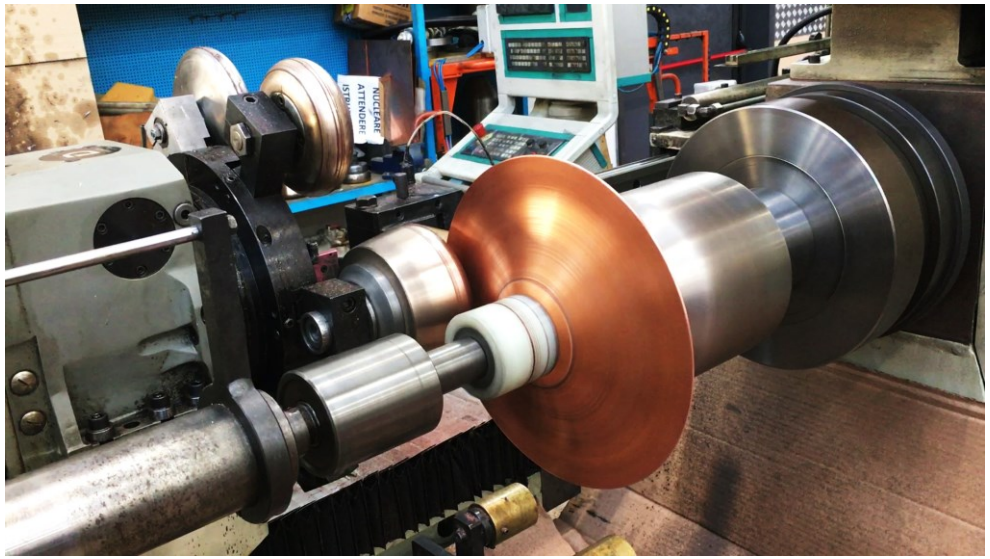
Two Copper 400 MHz **seamless Prototype** realized

Seamless Cavity Fabrication @LNL

On-going R&D

CNC Machine process evaluation on 1.3 GHz cavities to increase process reproducibility and geometrical accuracy of seamless spinning

INFN LNL · Università degli Studi di Padova · Piccoli srl



iFAST WP9 WP10

Proof of concept of **additive manufacturing** production for **SRF** applications on 6 GHz cavities

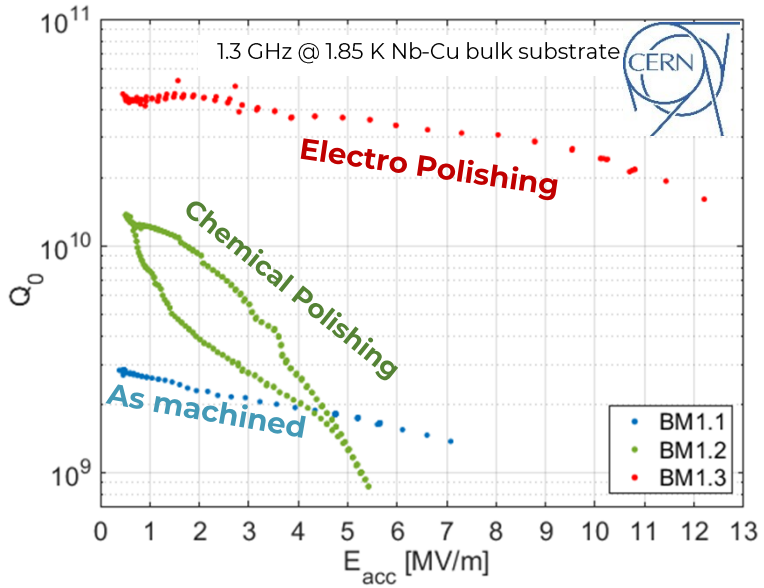
INFN Padova · INFN LNL

Nb on Cu R&D

Cu substrate plays a fundamental role in SRF performances

Cavity fabrication

Surface preparation



L. Vega Cid, TTC meeting 2022 (elaborated)

Roughness and defects reduction by **surface treatments are mandatory** for a good and uniform SRF coating

Cavity polishing requires **large amount of acids**. In particular **Nb** requires **HF** (extremely dangerous and poisoning process)

Plasma Electrolytic Polishing @LNL

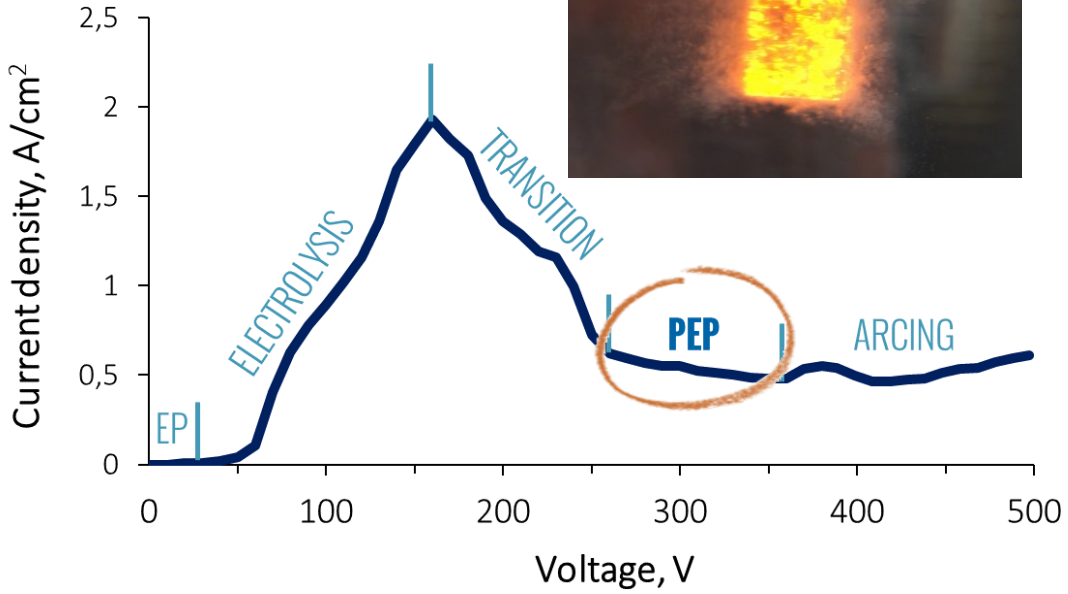
On-going R&D SAMARA

CSN5 INFN experiment

Identical EP set-up

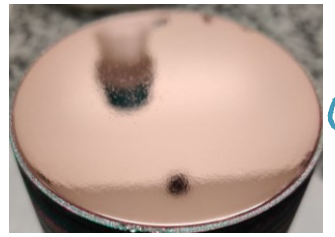
Different I-V conditions

Diluted salts solutions



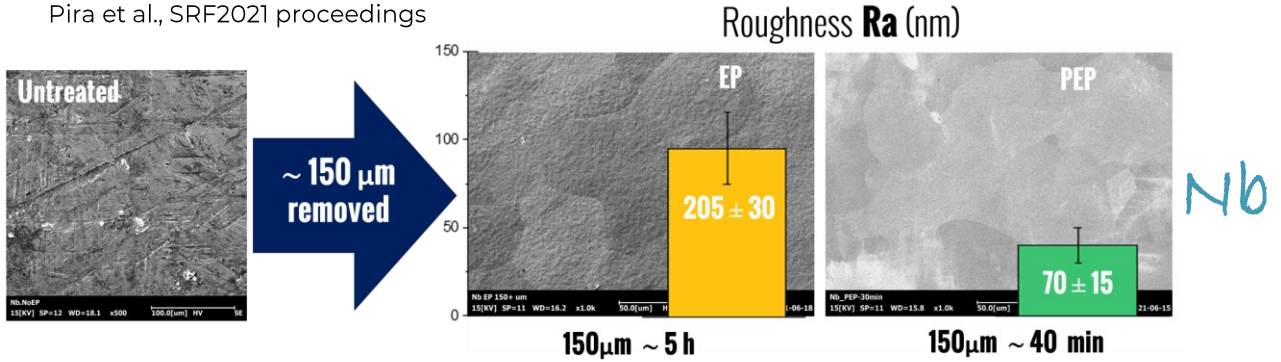
30 micron

4 min



Cu

Pira et al., SRF2021 proceedings



Nb

Compared to standard electropolishing:

10 times faster and 3 times more efficient

Safer and more eco-friendly than EP

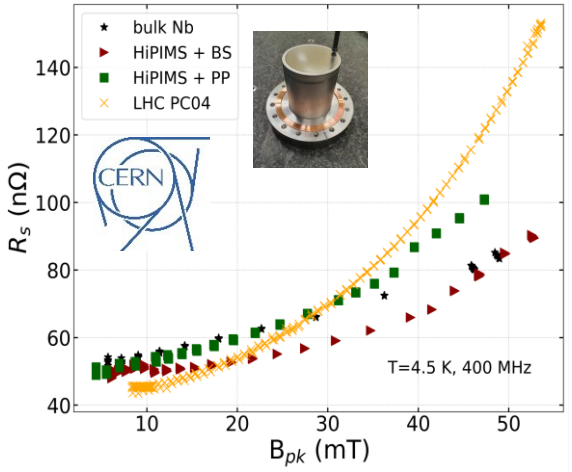
Polishing of large areas challenging

Nb on Cu R&D

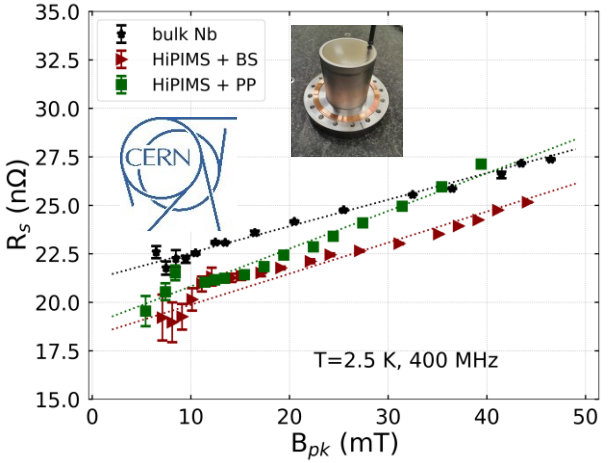
Marco Arzeo *et al* 2022 *Supercond. Sci. Technol.* in press
https://doi.org/10.1088/1361-6668/ac5646

Q-slope has been shown to be partially due to porosities present in the films.

Energetic Condensation Techniques (ECR, HiPIMS) increase film density



Q slope mitigation



Rs = 9-18 nΩ @ 2 K

Sputtering technology offers a wide range of optimization

Nb coating densification

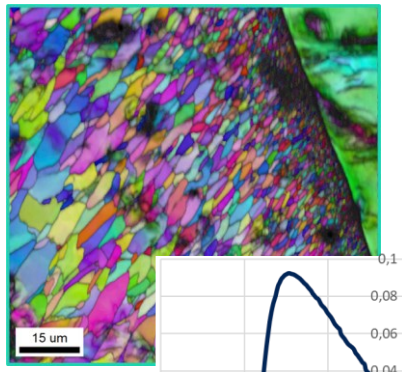
Nb on Cu Thick Films @LNL

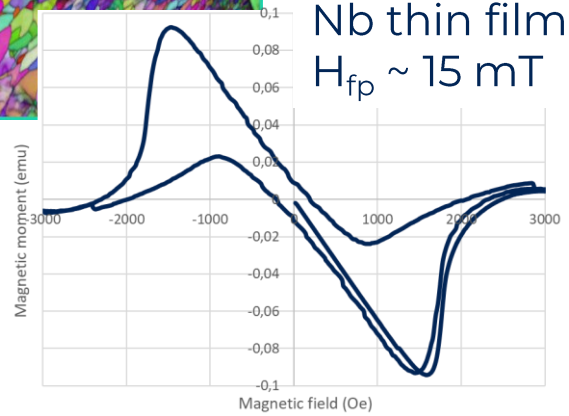
TEFEN CSN5 INFN experiment

EASITrain

LNL Approach for densification:

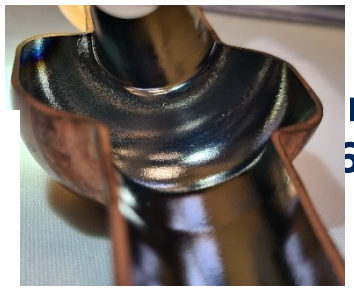
Thick film (>40 μm) + High Substrate T (550 °C)





Nb Thick film:
H_{fp} ~ 145 mT
Nb thin film
H_{fp} ~ 15 mT

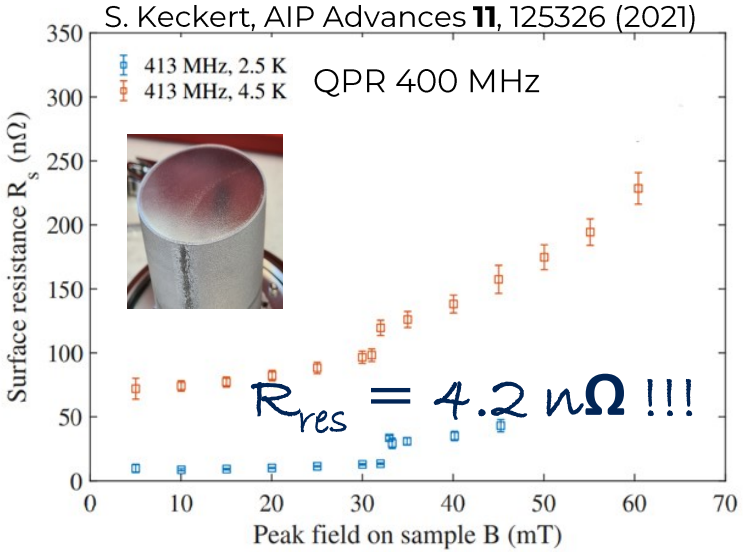
EBSD and Magnetometry on Thick film **6 GHz cavity** courtesy of STFC



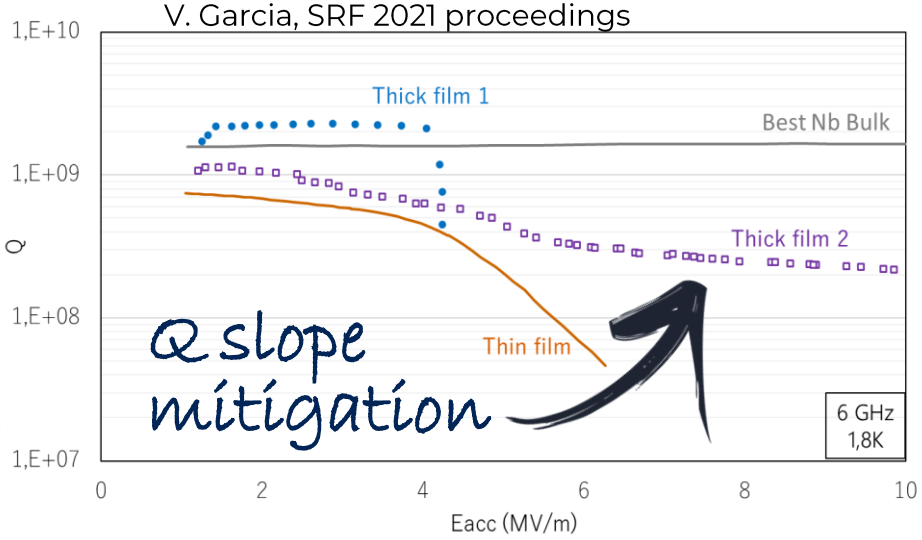
nvestigation on
6 GHz cavities

Nb Bulk Like Properties

S. Keckert, AIP Advances **11**, 125326 (2021)



V. Garcia, SRF 2021 proceedings



Coated cavities R&D

Nb_3Sn looks a good choice

Material	Tc	H_{sh}
Nb	9.2 K	0.2 T
Nb_3Sn	18.3 K	0.4T

DOUBLE ACCELERATING FIELD

60% DECREASE IN CRYOGENIC COSTS

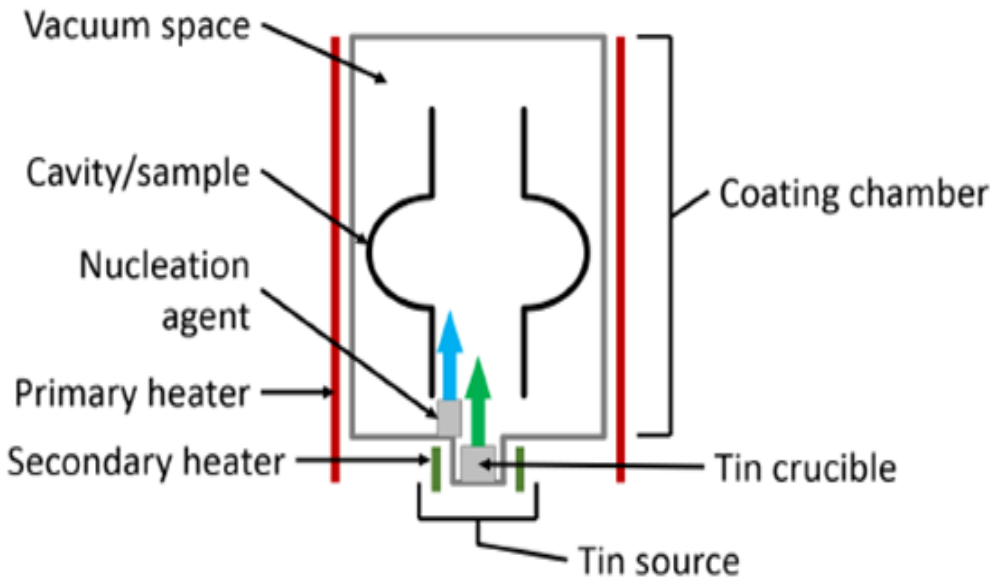
Sputtering technology offers a wide range of optimization

Nb coating densification

"Better SC" coating

Nb_3Sn State of the art

Vapour Tin Diffusion

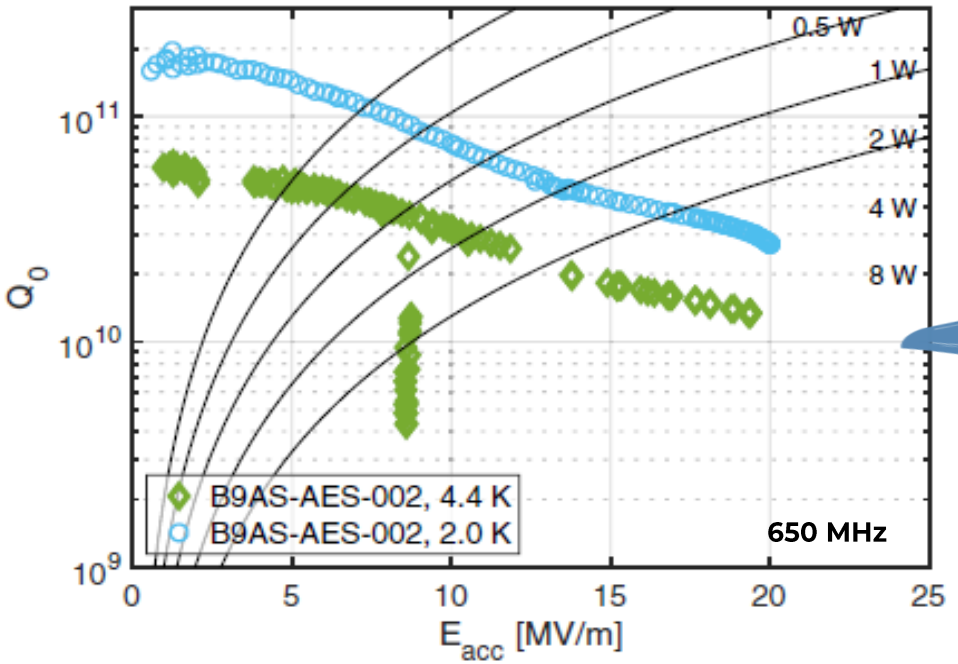


Nb_3Sn State of the art

Main limit

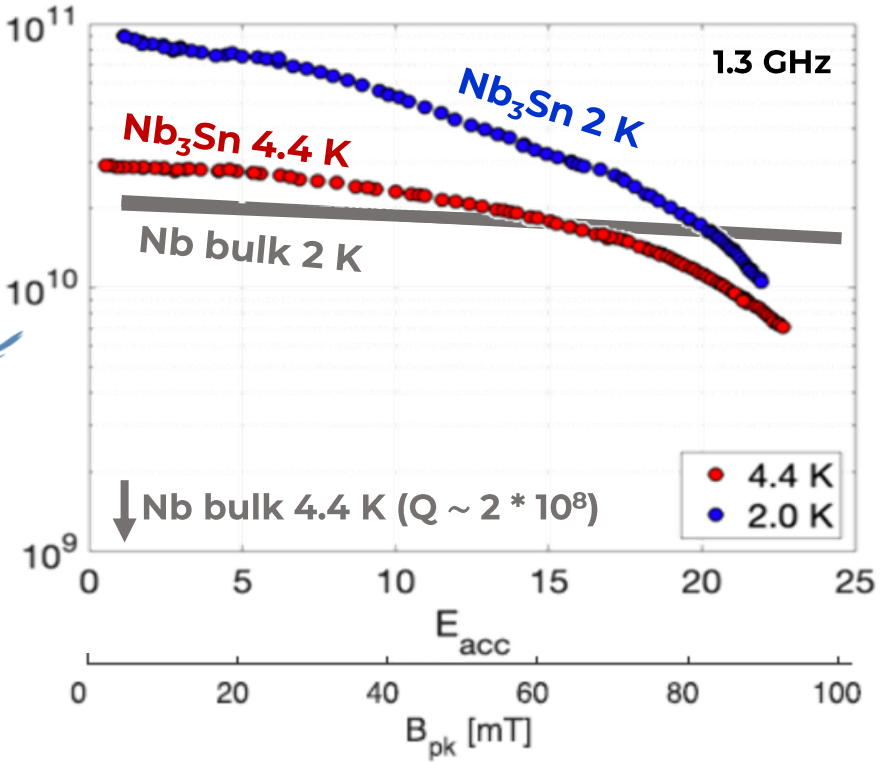
Needed Nb bulk cavities
Not possible on **Cu**

Vapour Tin Diffusion
Q_0 @ 4.4 K comparable to Nb bulk @ 2K



S. Posen, SRF 2019 proceedings

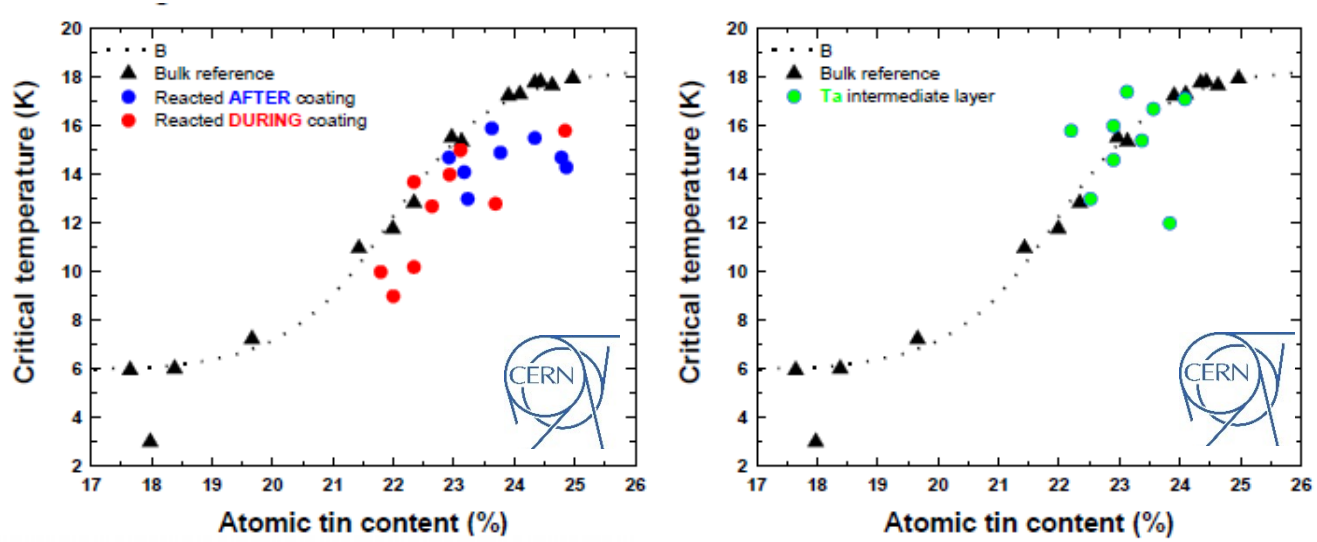
Low frequency
650 MHz



S. Posen, SRF 2019 proceedings (elaborated)

Nb_3Sn on Cu by Sputtering

- R&D @ CERN and others
- Good Tc
- Few RF test yet



Scale up will be challenging!

(cylindrical target not available)

Nb_3Sn on Cu by Sputtering @ LNL

On-going R&D

iFAST WP9

SAMARA
CSN5 INFN experiment

GOAL:
1.3 GHz Nb_3Sn on Cu elliptical cavity ready in 2025

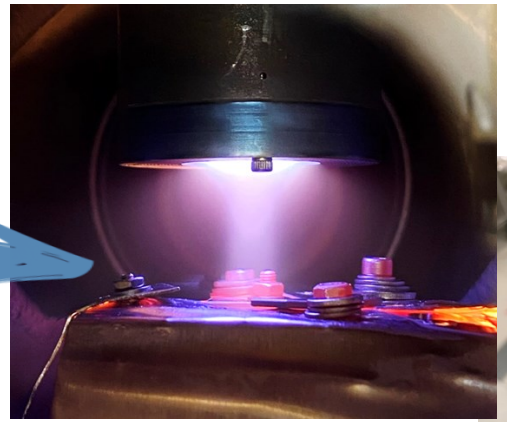
Exploration of different scale up configurations
on 6 GHz and 1.3 GHz cavities

Nb_3Sn on Cu by Sputtering @ LNL

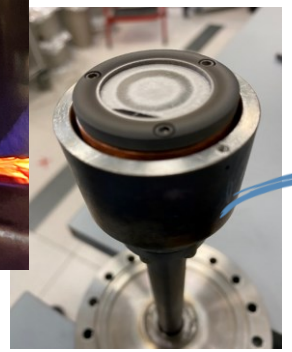
Nb_3Sn target by Dipping

Proof of concept successfully done:

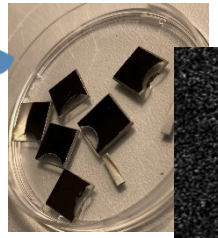
Up to 50 microns Nb_3Sn
on 1" Nb planar target

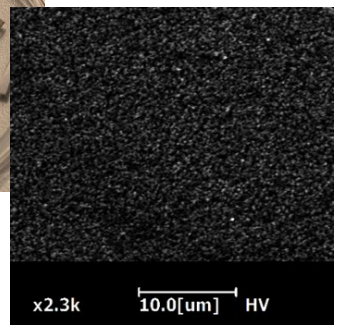


Coating on Quartz by
Magnetron Sputtering



1 microns Nb_3Sn
76% Nb – 24% Sn (EDS)





Zanierato et al,
SRF Proceedings 2021

Next step: cylindrical target for 6 GHz cavities

Conclusions

Many possible **points of common interest** for a **collaboration** in FCC, in particular regarding **coating cavities,** on:

- **Forming technology**
- **Surface Preparation**
- **Nb and Nb_3Sn coatings**

Thank you!

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EASITrain This Marie Sklodowska-Curie Action (MSCA) Innovative Training Networks (ITN) receives funding from the European Union's H2020 Framework Programme under GA no. 764879

INFN