This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under GA No 101004730.

Cristian Pira

INFN

HTS R&D for SRF cavities

Industry Workshop on HTS developments and applications

NH Trieste, 18 Apr 2023, 2nd iFAST annual meeting

iFAST

Outline

Introduction to SRF and difference with Magnets

State of the art in SRF

Motivation for HTS in SRF

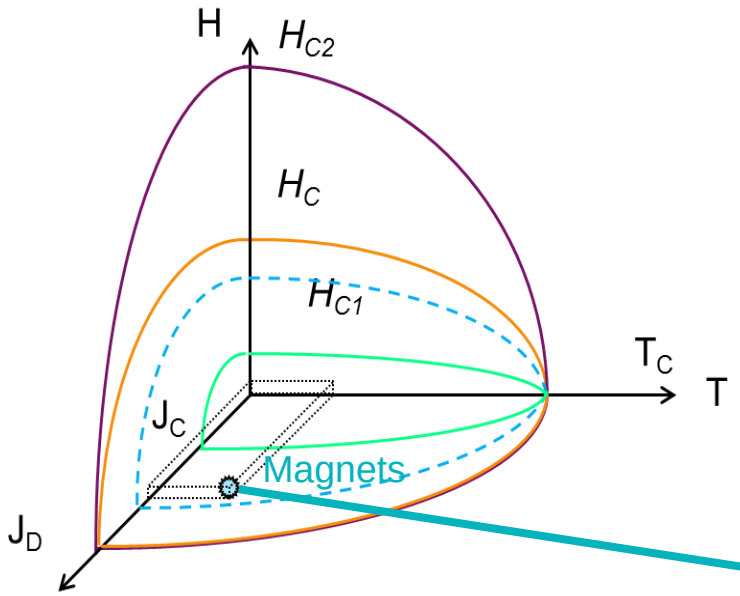
HTS materials for SRF and state of the art

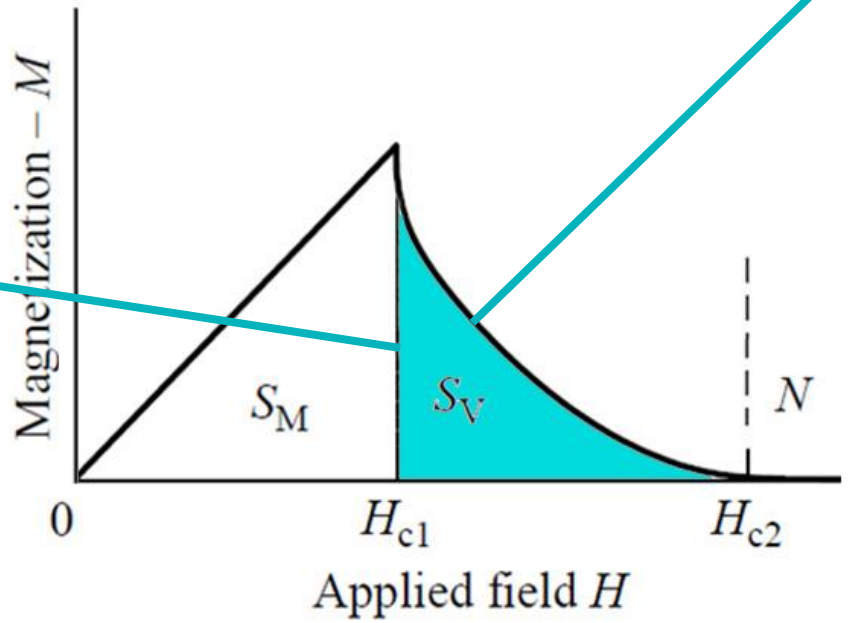
Industrial applications for HTS SRF cavities

I.FAST R&D

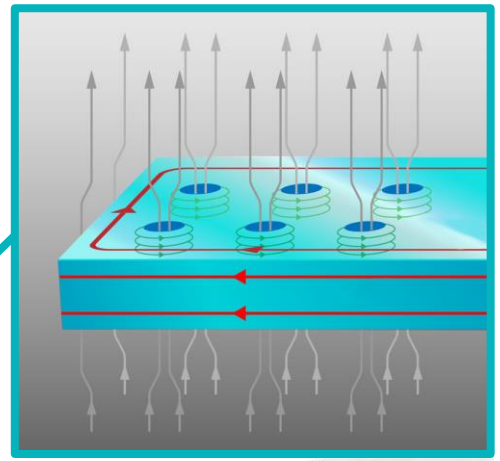
Opportunities for industrial partners

Superconducting Magnets





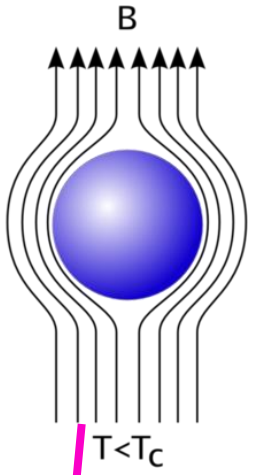
Mixed State, Vortex



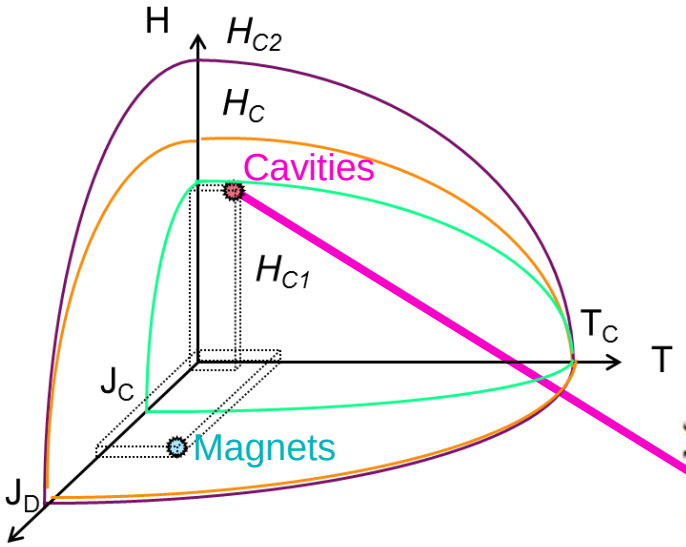
Nb_3Sn ITER cable

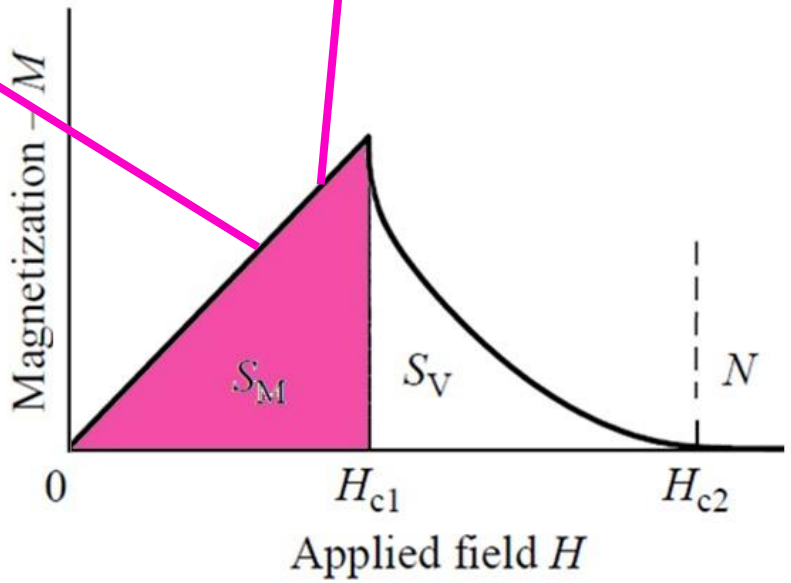
REBCO cable prototype, CERN

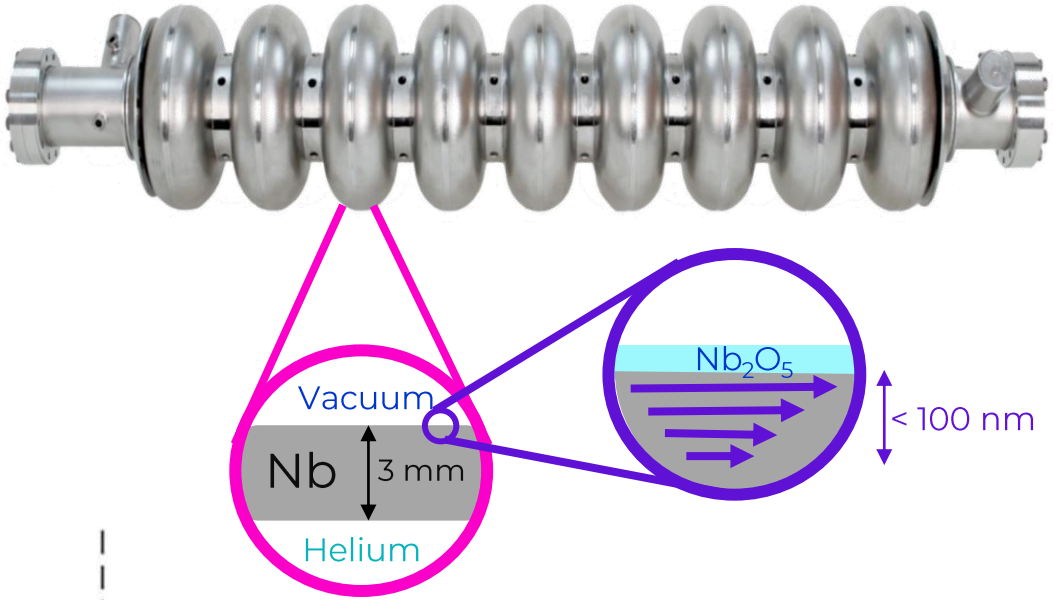
SRF Cavities



Complete Fux Expulsion







RF interact only with 100s of nm on the **surface**

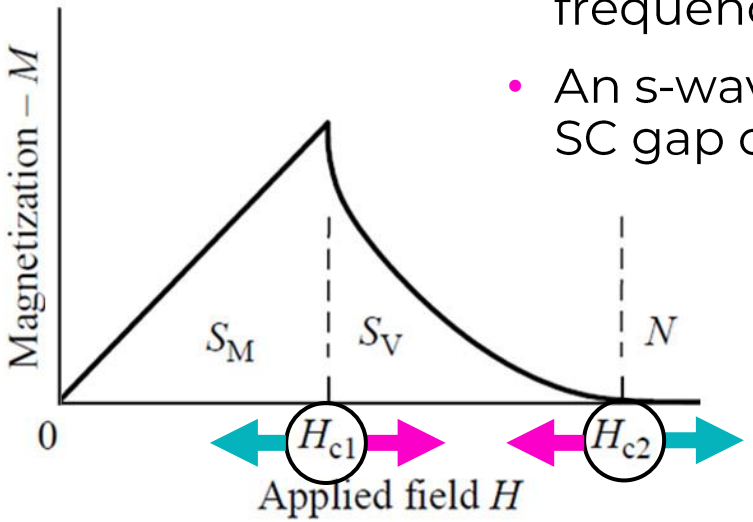
Different regime means different materials

Good SC for magnet application are bad for cavities!

Magnets – DC

- High current densities with 0 resistance
- Mixed State

Defects are voluntarily introduced to **enhance pinning**



Cavities – RF

- very high field with minimal dissipation (10-20 nΩ @1.3 GHz)
- Vortices cannot keep pinned at this frequency → **Meissner State**
- An s-wave Cooper pairing state with a full SC gap on the entire Fermi surface

Emphasis is placed on **reducing** the number of **defects**

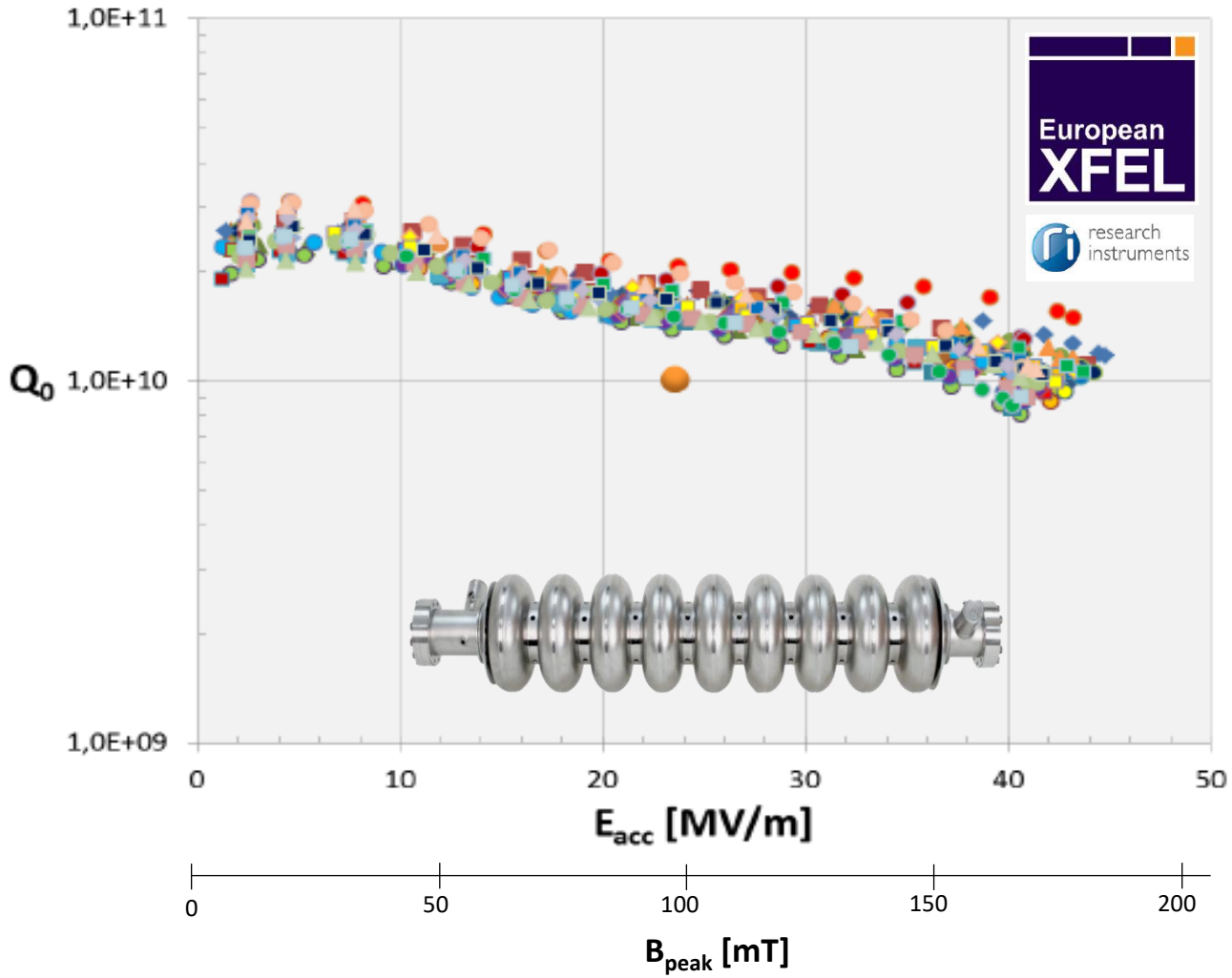
State of the art: Bulk Nb

Performances closer to Nb theoretical limits

$H_{SH} \sim 200$ mT

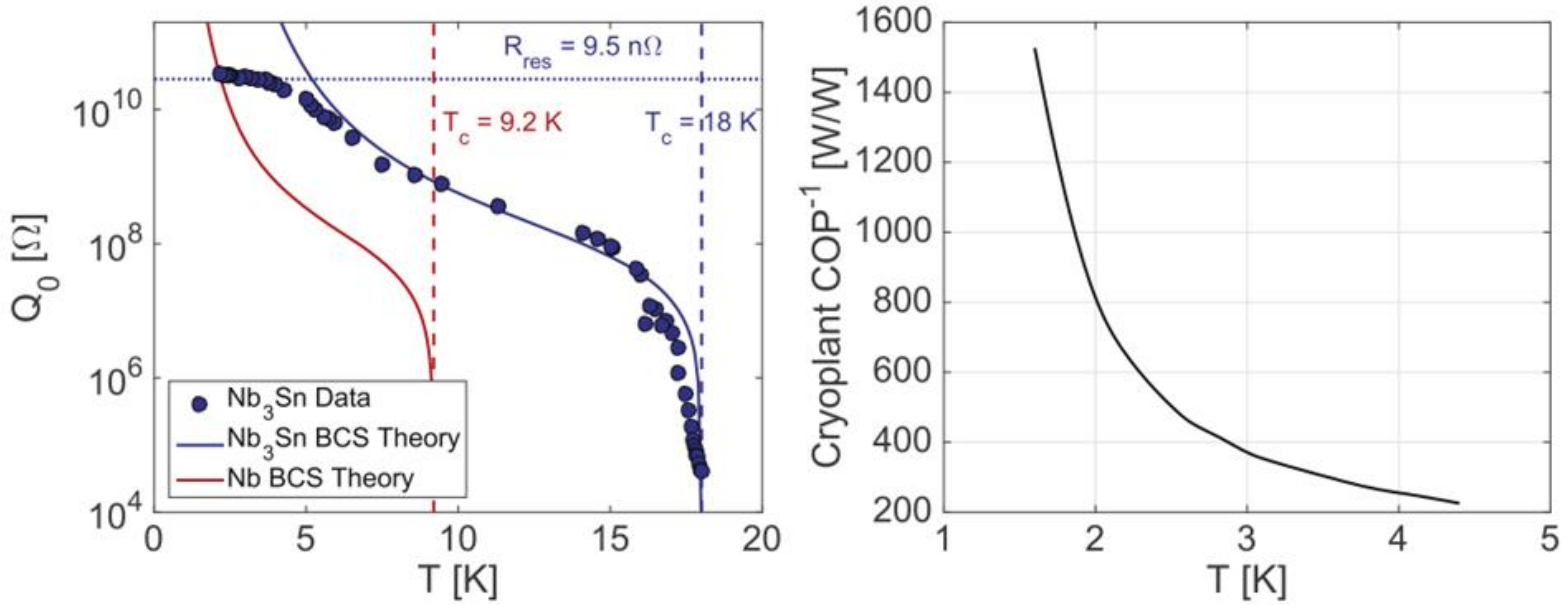
Because **Tc of Nb is 9.2 K**

SRF cavities are operated at **2 K for High Q**



Energy saving push for HTS R&D

Increase Tc means move operational T from 2K to 4.5 K



Supercond. Sci. Technol. 30 (2017) 033004

Reduces cryogenic power by a factor of 3

HTS candidates and current R&D

HTS in SRF means SC with T_c > T_c Nb

Nb_3Sn

Tc = 18.3 K

Vapor/Liquid Tin Diffusion
Sputtering
Co-sputtering, Bronze route
Electrochemical deposition

MgB_2

Tc = 39 K

Hybrid Physical Chemical Vapor Deposition, In-situ reactive evaporation, Plasma electrolytic oxidation

NbTiN

Tc = 17.3 K

Sputtering, plasma-enhanced ALD

V_3Si

Tc = 17.1 K

Sputtering, Thermal Diffusion

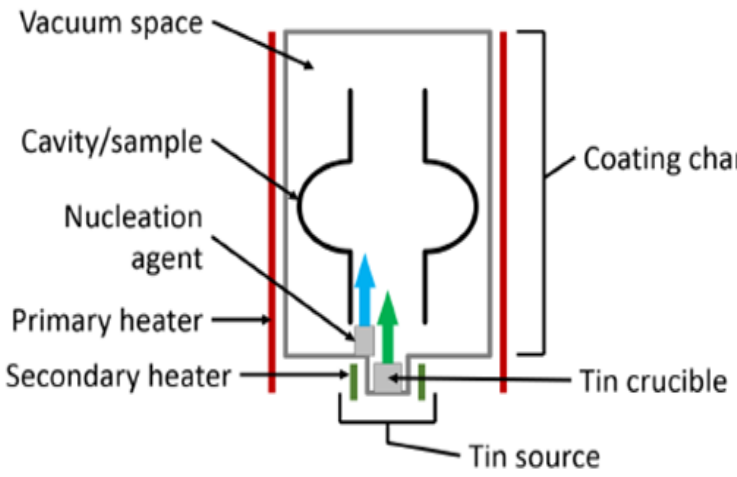
Very brittle materials

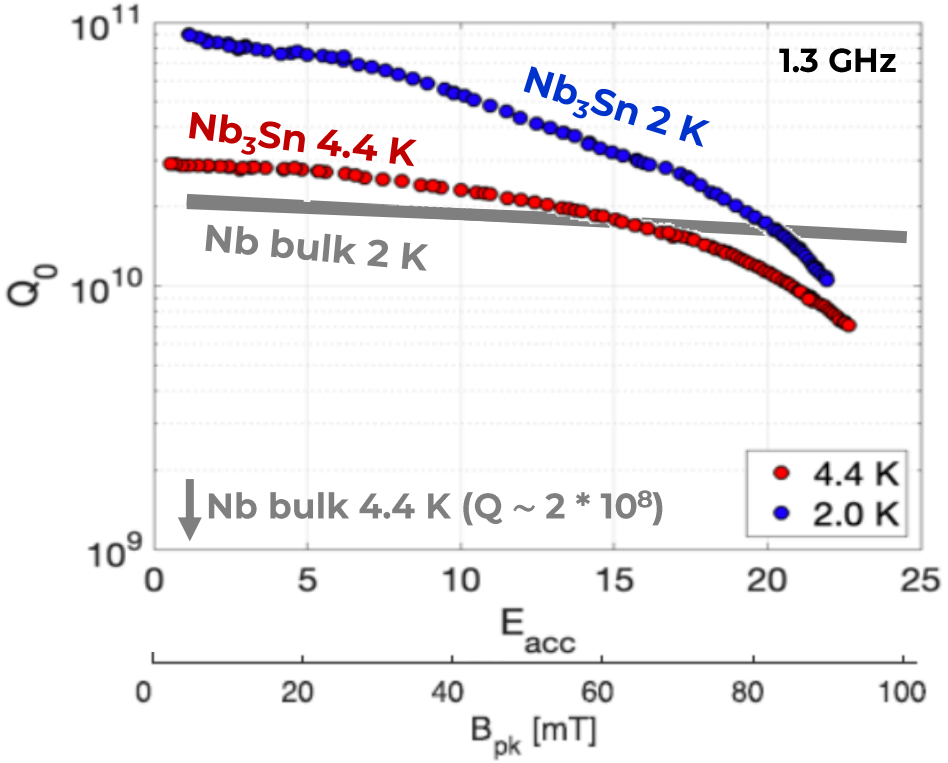
Only thin films possible

Nb_3Sn state of the art

Vapor Tin Diffusion

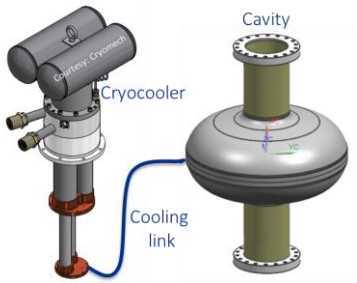
Cornell, Fermilab, Jlab, KEK





S. Posen, SRF 2019 proceedings (elaborated)

Conduction cooled SRF for industrial applications



4.5 K operation with high Q open the possibility to simplify cryogenics using cryocoolers instead of He bath

Courtesy: Jayakar Thangaraj

650 MHz, welded niobium rings @ Fermilab

Courtesy: John Vennekate

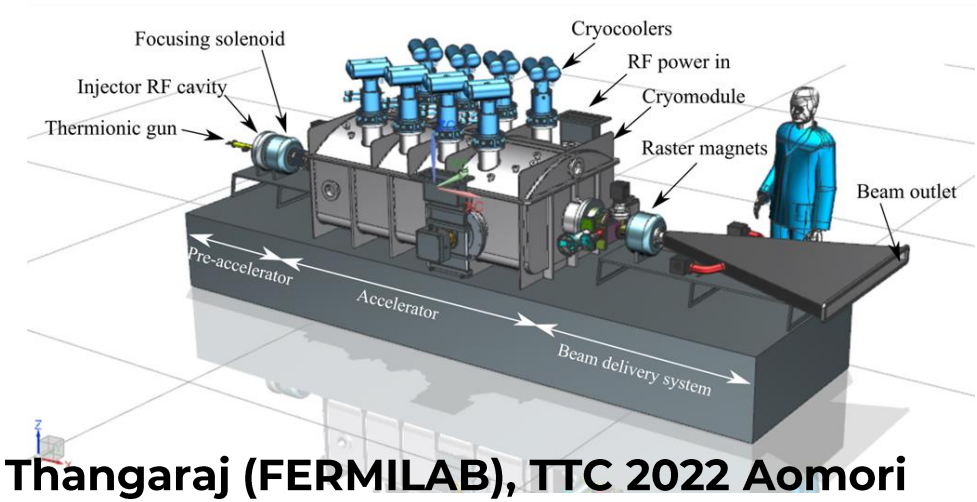
1.3 GHz , Cu plating & ring @JLab

ENERGY AND ENVIROMENT

- Treat Municipal Waste & Sludge
- In-situ environmental remediation

INDUSTRIAL AND SECURITY

- In-situ cross-link of materials
- Medical sterilization without Co60



Jayakar Thangaraj (FERMILAB), TTC 2022 Aomori

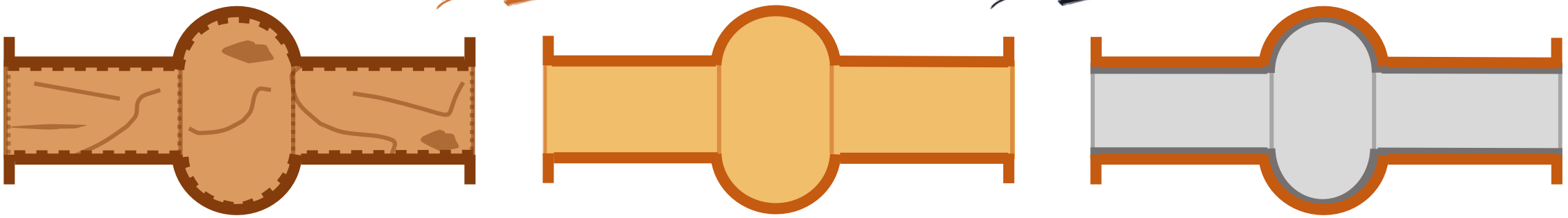
A different approach on I.FAST: Nb_3Sn on Cu

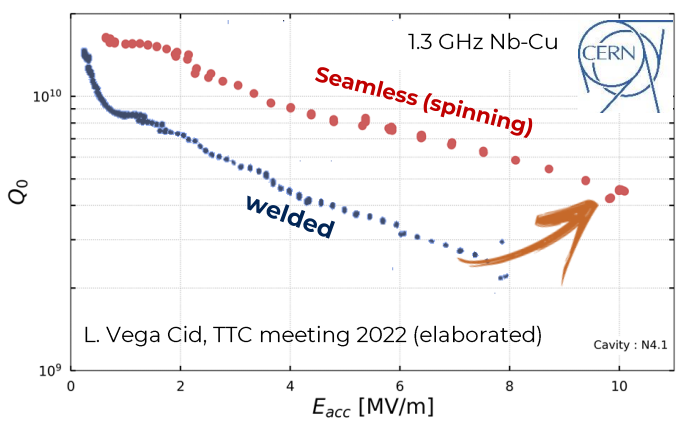
Cu substrate as several advantages:

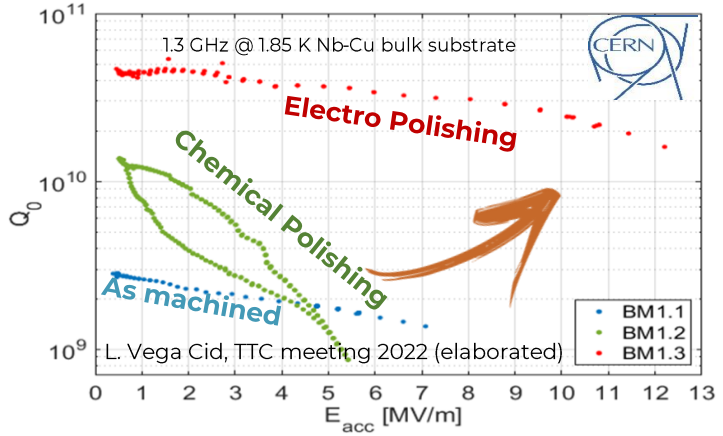
- Cheaper than Nb
- Higher thermal conductivity
- PVD technology (Nb on Cu) already used for LEP, LHC, HIE-ISOLDE @ CERN
  ALPI @ INFN LNL

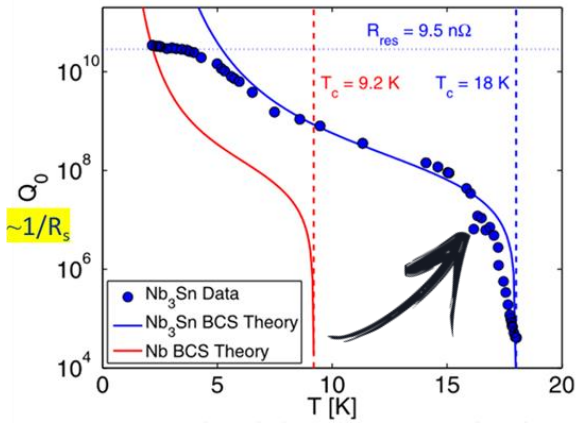
R&D on all the production chain

Cavity Forming → Surface Polishing → SC Coating

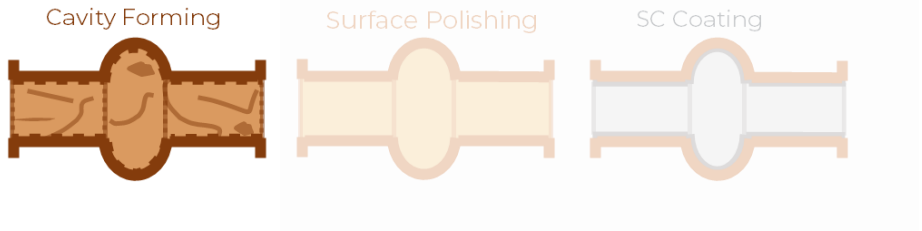




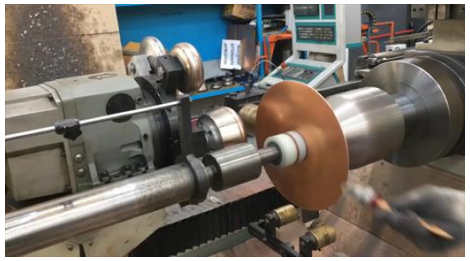




R&D on Seamless Cavity Fabrication



Spinning (WP9)



1.3 GHz seamless copper production by spinning

Sciarrabba et al, SRF2021 proceedings

400 MHz seamless copper Prototype

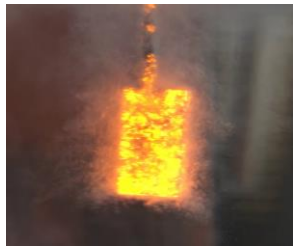
additive manufacturing (WP10)

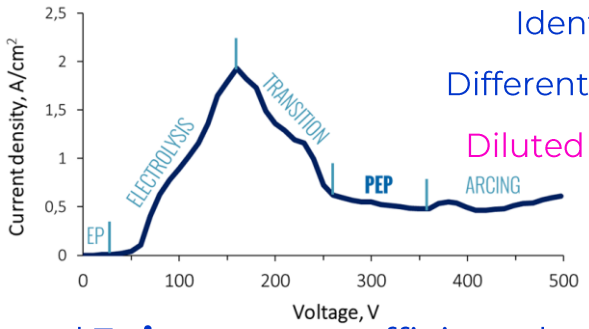
Candela V. *et al.* Smoothening of the down-skin regions of copper components produced via Laser Powder Bed Fusion technology. *Int J Adv Manuf Technol* **123**, 3205–3221 (2022)

R&D on Surface Polishing

Plasma Electrolytic Polishing

(WP9)



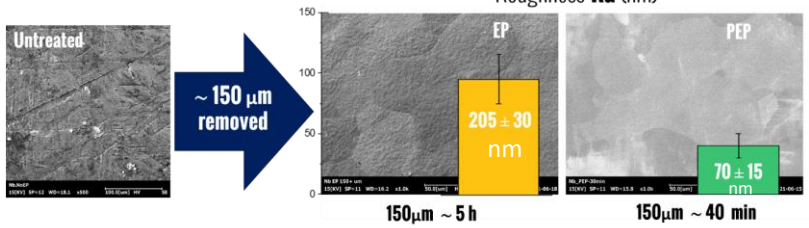


Identical EP set-up

Different I-V conditions

Diluted salts solutions (INFN patent)

- **10 times faster** and **3 times more** efficient than standard EP
- **Safer** and more **eco-friendly** than EP
- Polishing of large areas challenging



Pira et al., SRF2021 proceedings

Mechanical polishing for AM

(WP10)

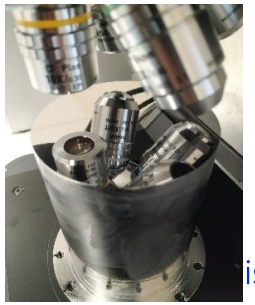
3 Step process:

1. Mechanical Treatment
   R_a ~ 30 µm → ~ 4 µm
2. Chemically assisted
   R_a ~4 µm → R_a <1 µm
3. Final polishing
   R_a ~0.5 µm

Candela V. *et al.* Smoothening of the down-skin regions of copper components produced via Laser Powder Bed Fusion technology. *Int J Adv Manuf Technol* **123**, 3205–3221 (2022)

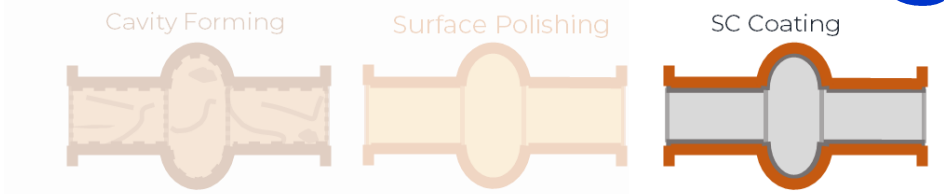
Metallographic polishing

(WP9)



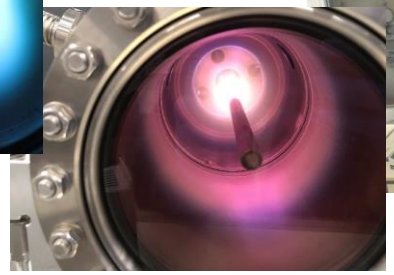
Mirror like mechanical polishing

R&D on Coatings

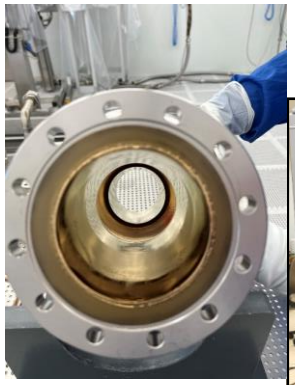


HTS COATINGS BY PVD (WP9)

Nb_3Sn, NbTiN

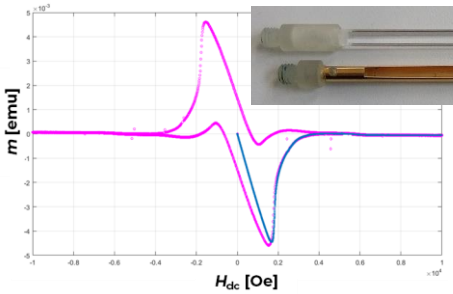


NANO COATINGS BY ALD (WP9)



- Protective barrier
- Adaptive layer
- Low SEY material
- SIS multilayer

CHARACTERIZATION (WP9)

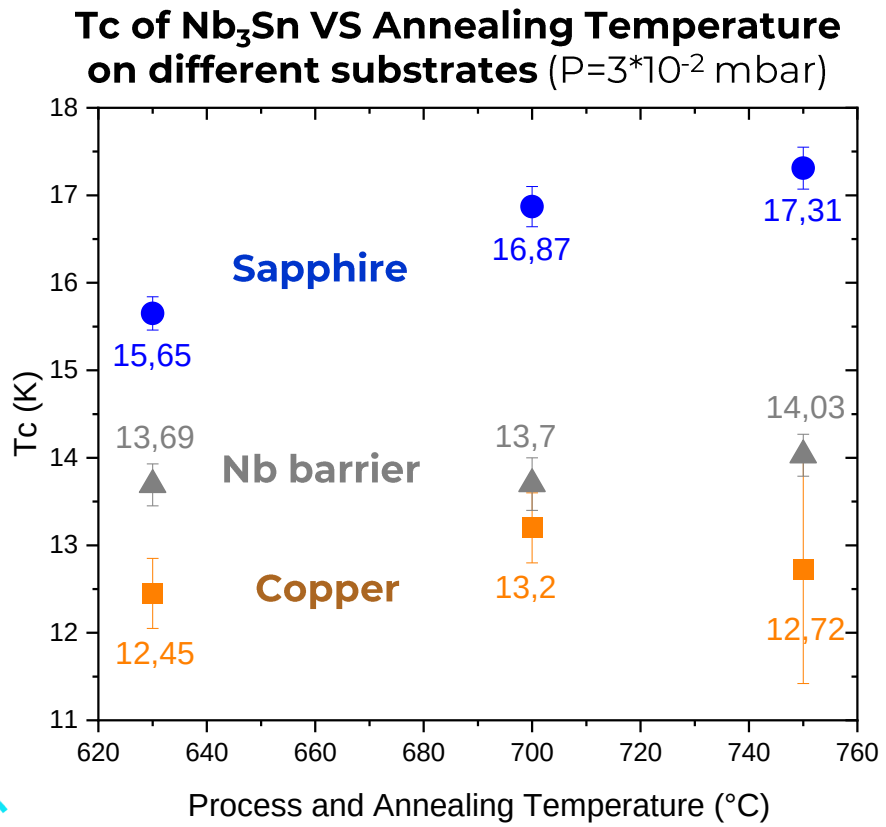


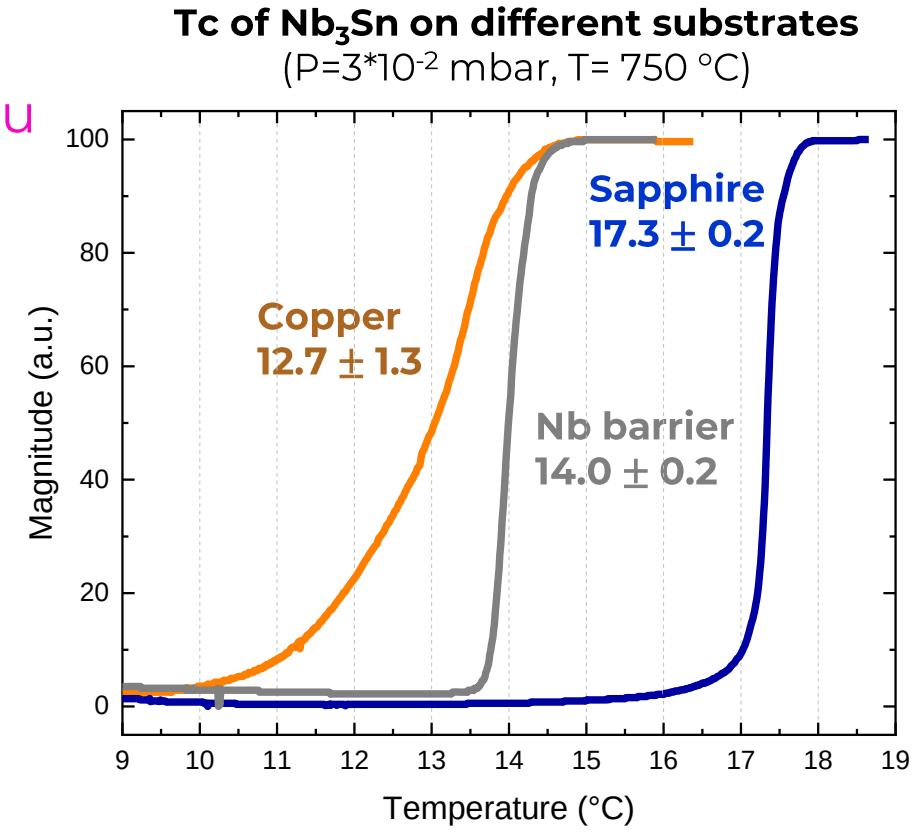
- Magnetometry
- Penetration field
- QPR
- 6 GHz cavities
- Choke and split cavities

Nb_3Sn on Cu is a challenge!

Low melting point of Cu is a limitation

Diffusion of Cu into Nb_3Sn and Sn migration into Cu

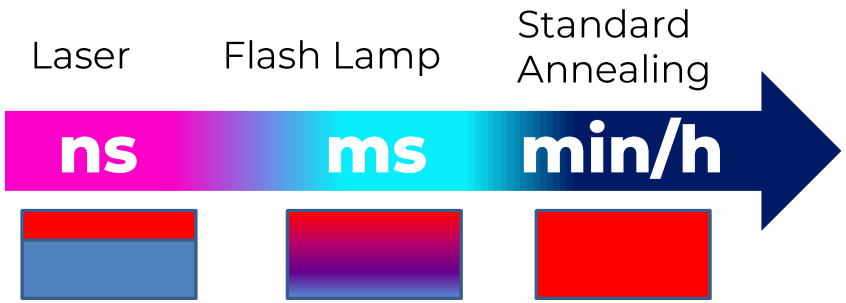




A barrier layer slightly improves Tc

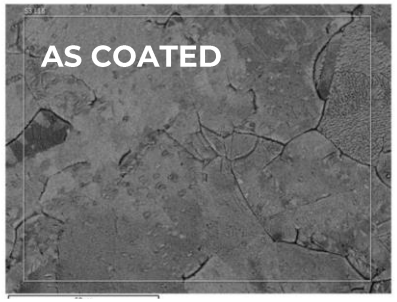
Other solutions?

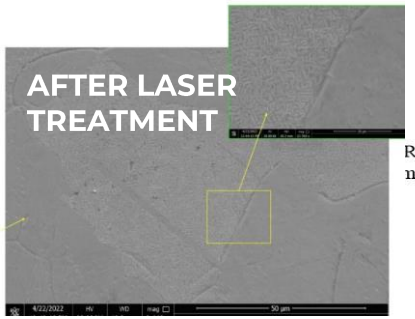
Fast annealing



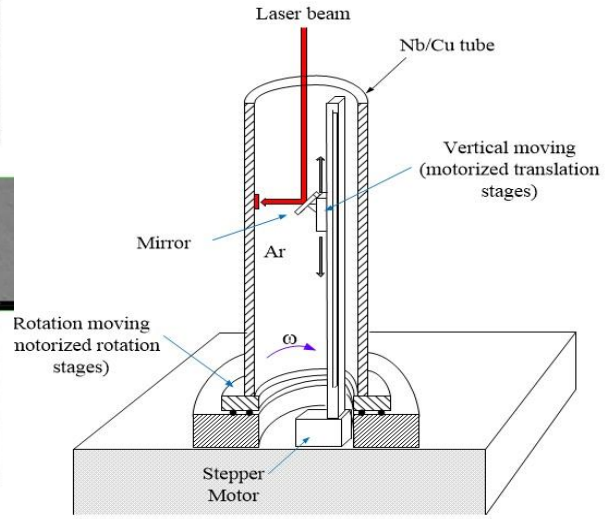
LASER ANNEALING

(WP9)





RIGA TECHNICAL UNIVERSITY



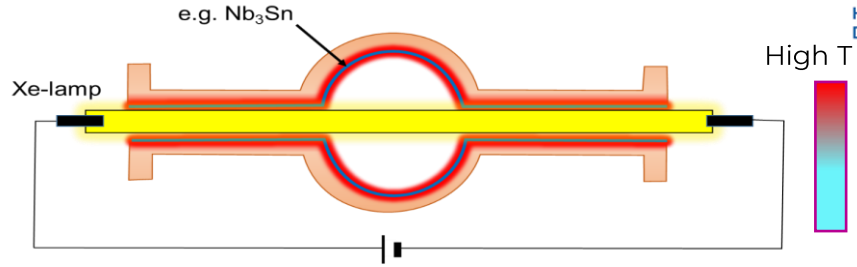
R Ries et al 2021 Supercond. Sci. Technol. 34 065001

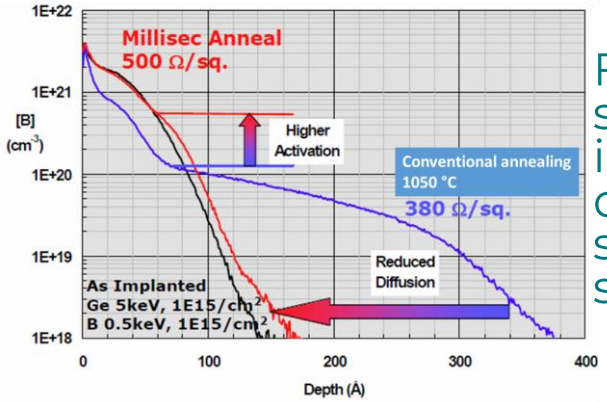
D. A. Turner et al 2023 IEEE Transactions on Applied Superconductivity 33 7500512

FLASH LAMP ANNEALING

(IIF project)

HZDR HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF



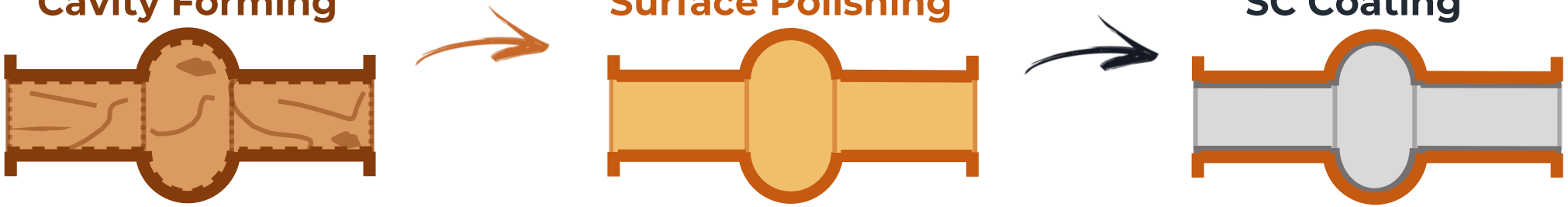


FLA is used in semiconductor industry to reduce diffusion of dopants in substitution of standard annealing

There is room for industrial companies

3 main topics/areas for potential collaboration with industries

Cavity Forming → **Surface Polishing** → **SC Coating**



2 companies are already involved in I.FAST WP9 and WP10:

PICCOLI srl – TORNERIA IN LASTRA METALLICA

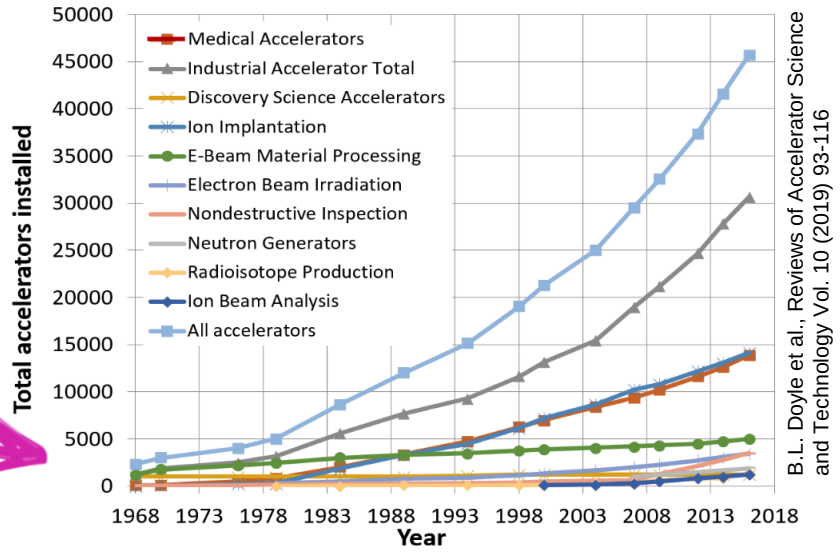
Seamless cavity forming by spinning

RÖSLER *finding a better way ...*

Mechanical polishing
of Additive Manufacturing Cavities

HTS SRF has the potential to enter a huge market
currently not accessible due to the complex cryogenics required by traditional Nb SRF cavities

Accelerators installed worldwide



B.L. Doyle et al., Reviews of Accelerator Science and Technology Vol. 10 (2019) 93-116

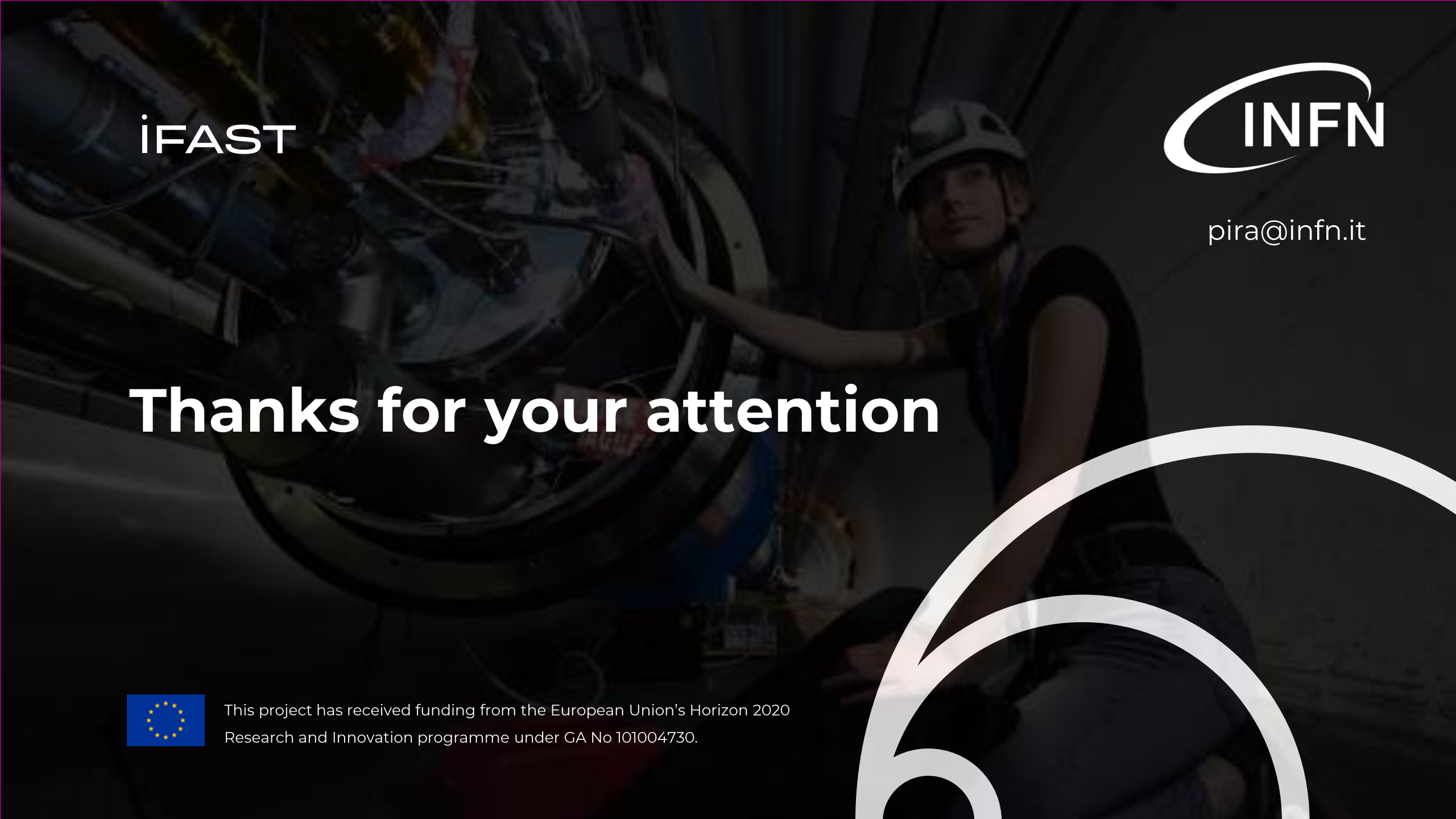
Conclusions

Nb_3Sn on Cu for SRF is a challenge

R&D still ongoing (TRL 2 → TRL 5)

3 main areas in which collaboration with industry can help

New market for SRF in the horizon



iFAST

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Thanks for your attention

This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under GA No 101004730.