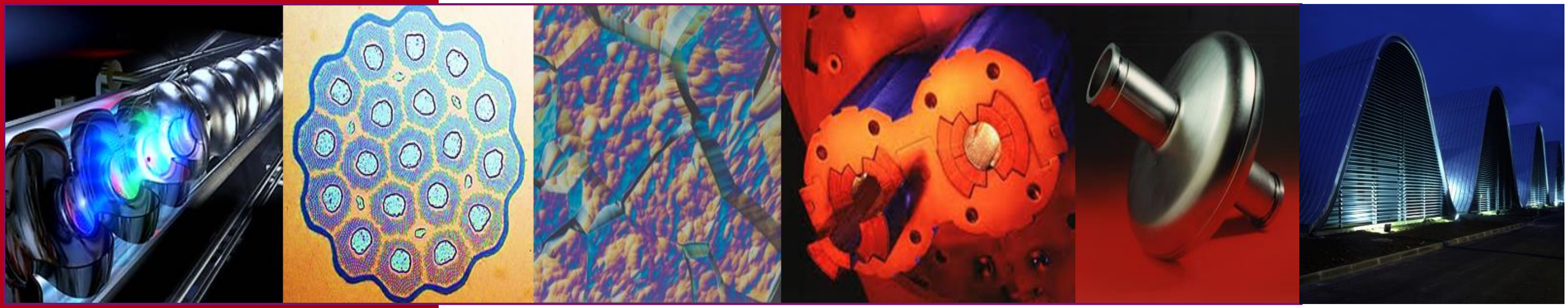
DE LA RECHERCHE À L'INDUSTRIE

Research Program for improving SRF cavity performances at CEA



Thomas Proslier

www.cea.fr

FCC - France

Research Program for improving SRF cavity performances at CEA

- Unique Characterizations tools
  - Point Contact Tunneling spectroscopy
  - Magnetometry
  - Predictive power for RF tests
- Thin films developements
- Bulk Nb infusion
- Chemistry: Vertical electropolishing
- Cobotization

Introduction

- **Reduce operation and construction cost of accelerators**

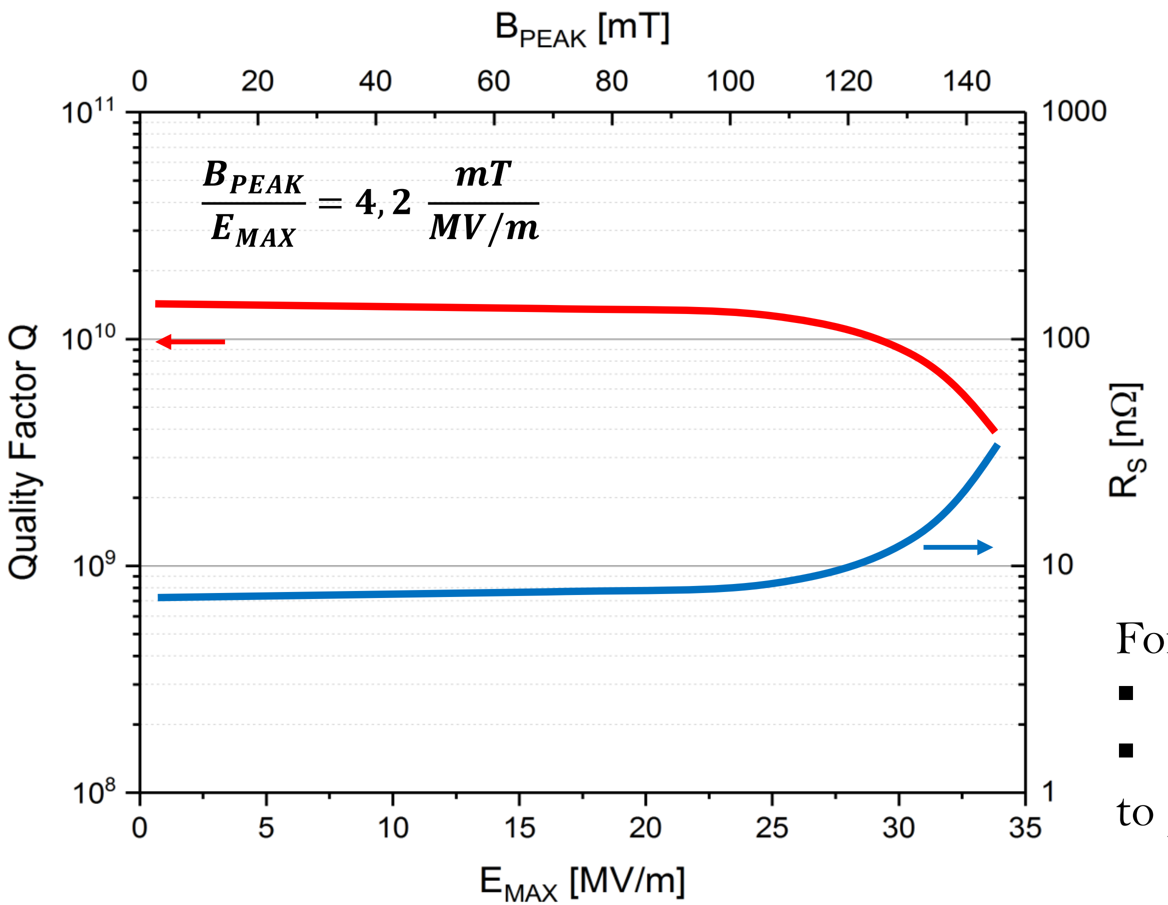
  In particular superconducting Nb cavities (bulk, heavy surface treatments)

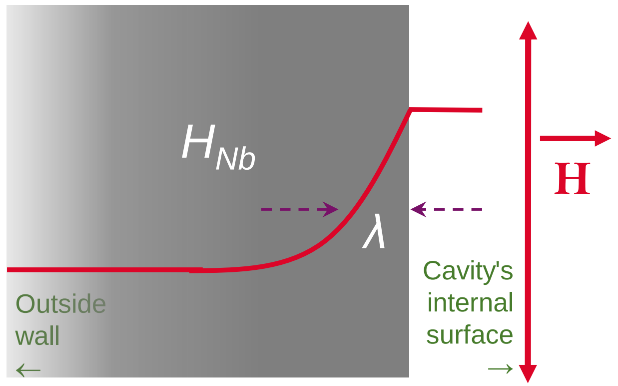
- Limit: **Bulk Nb is reaching intrinsic limits**
  - Great improvements on Q0 (doping) – FNAL, Jlab, Cornell, Desy, HZB, KEK
  - Some improvements on Emax to be confirmed (infusion) - FNAL, Desy, HZB, KEK

- Solutions:
  - Reduce the amount of Nb: Thin films on Cu - CERN, Jlab…
  - Increase operation temperature from 2 to 4,2 K: better superconductors Nb_3Sn - Cornell, FNAL, CERN
  - Increase performances: Q_0 and E_{MAX}, multilayer structure – CEA, STFC, INFN, IPNO, Desy, HZB

- Collaborating institutions:
  - France: IPNO: bulk Nb surface treatments; LAL: characterization; CERN: thin films
  - Japan: KEK: thin films, theory, electropolishing
  - Germany: HZB: characterization, thin films; DESY: characterization, thin films
  - England: STFC: thin films
  - USA: JLAB: Bulk Nb, thin films; FNAL: Bulk Nb, Nb3Sn; Cornell: Nb3Sn

$$Q_0 = \frac{Energie\ input}{Losses} = \frac{G}{R_S(B)}$$





For Nb, λ = 45 nm

- Surface properties dominate
- Whatever the solution, tools needed to probe the surface superconductivity.

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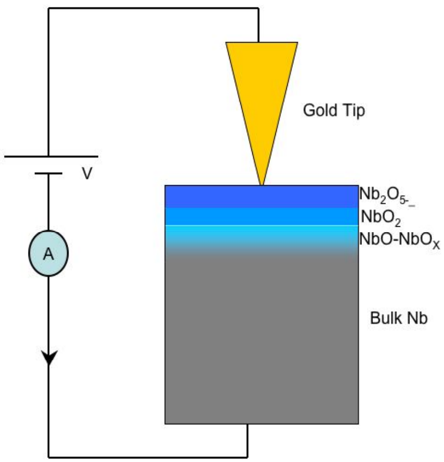
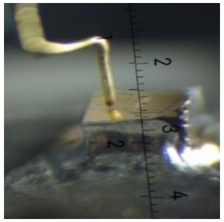
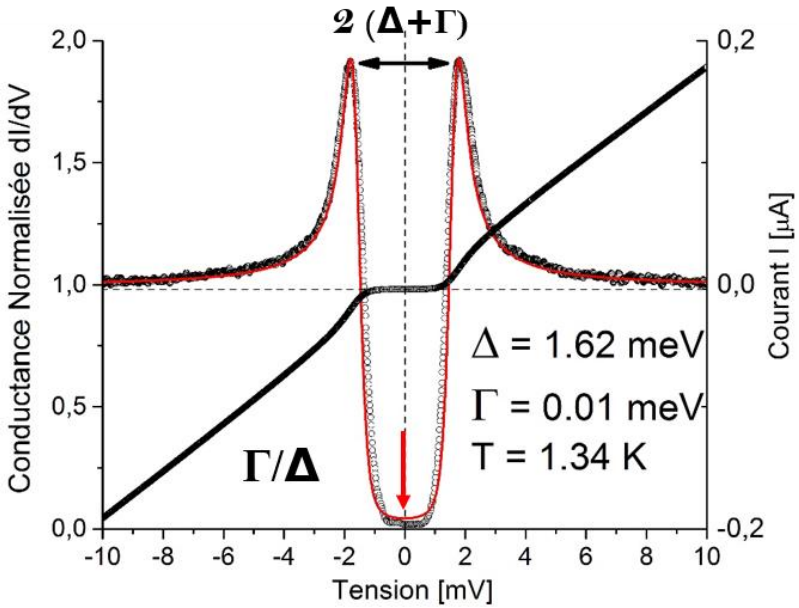
Tunneling spectroscopy: what do we measure and why?

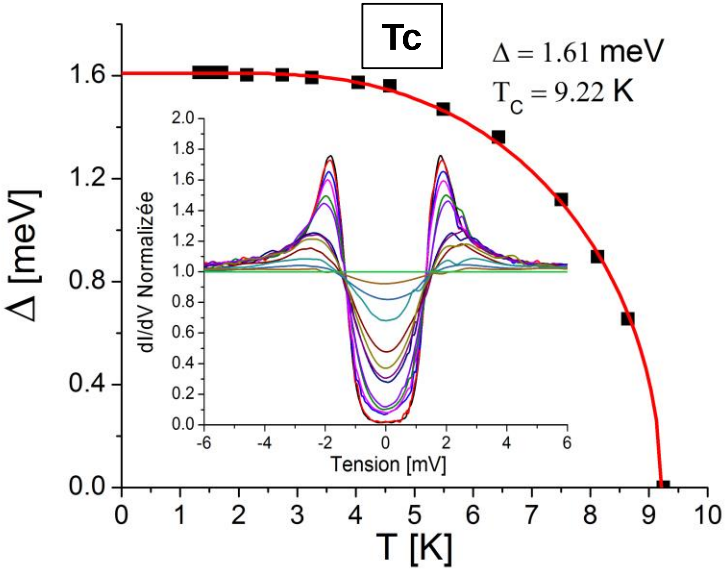
principle





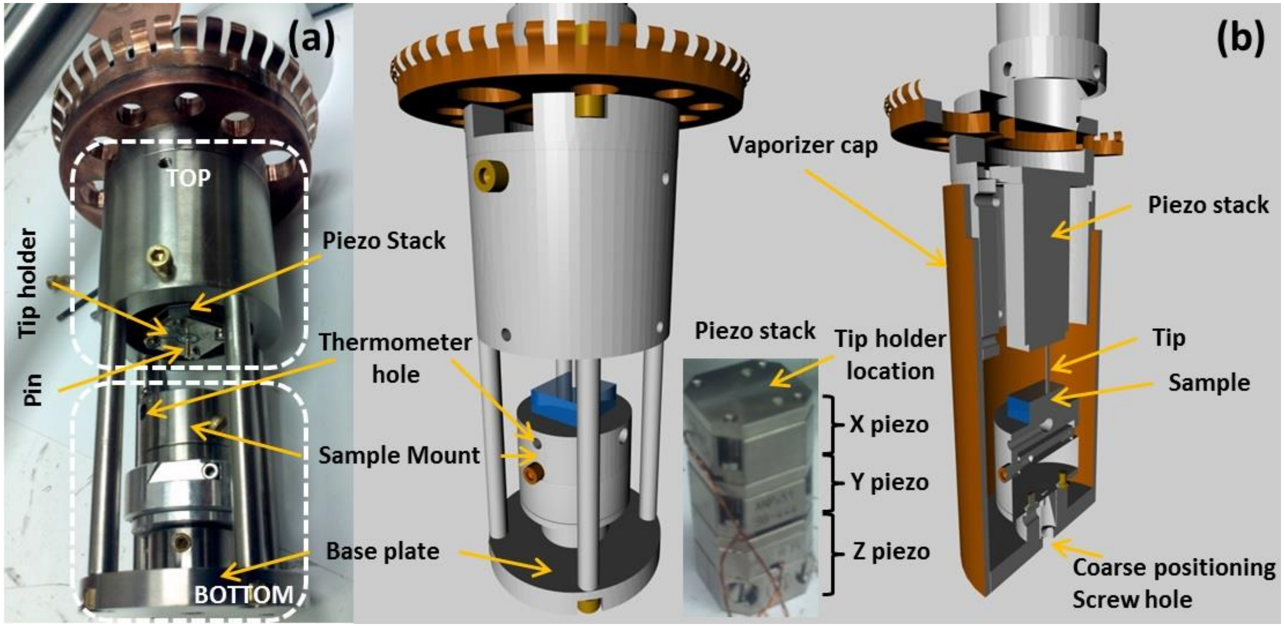
measure





- Measure the fundamental superconducting parameters: Δ, T_C, H_{C2}
- Measure non-ideal signature: Γ.
- All of these are directly correlated to SRF cavity performances
- Cartography

The Point Contact system at CEA



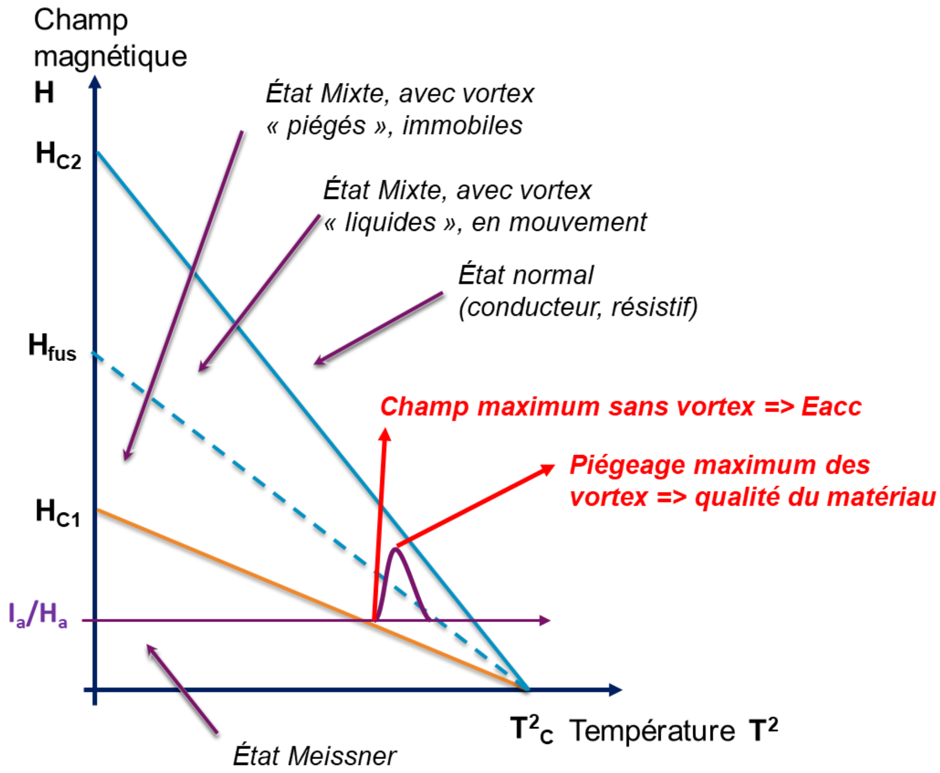
- Temp: 1,4 K – Magnetic field: 6 T
- Variable junction resistance: $2.10^2 – 2.10^9$ Ω.
- Cartography: 10 µm – 1 mm
- Fast measurements: 100-300 jonctions/5hrs
- Transport (RRR, Tc vs H applied...)
- Hall Effect
- Sample size: 10x10 mm

Used for thin films: Nb/Cu, Nb_3Sn, mutlilayers…

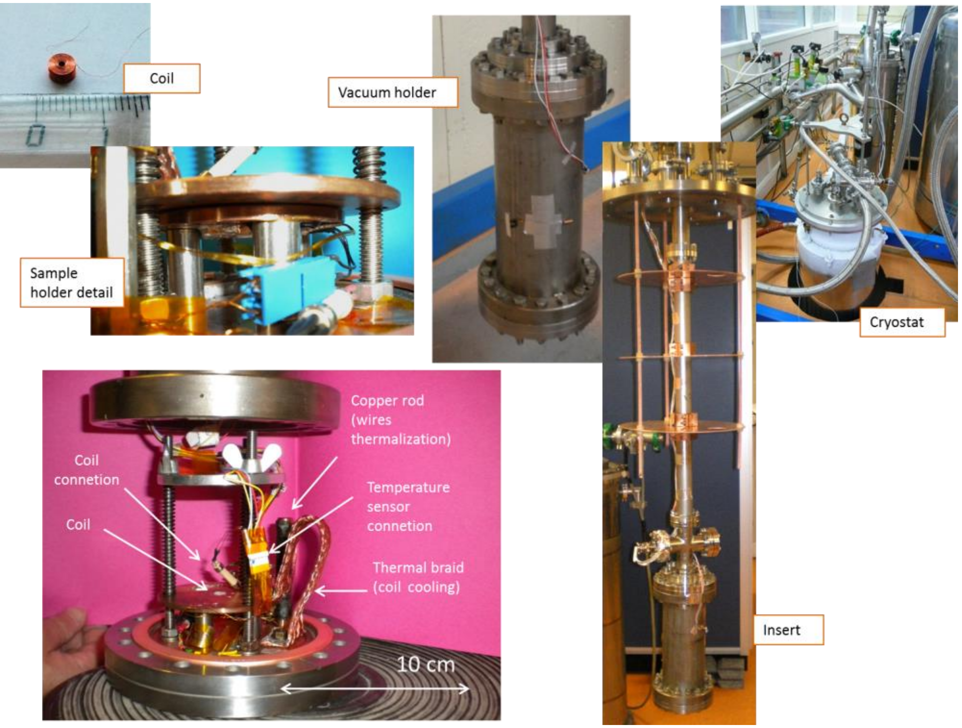
Bulk Nb surface treatments (doping, infusion…)

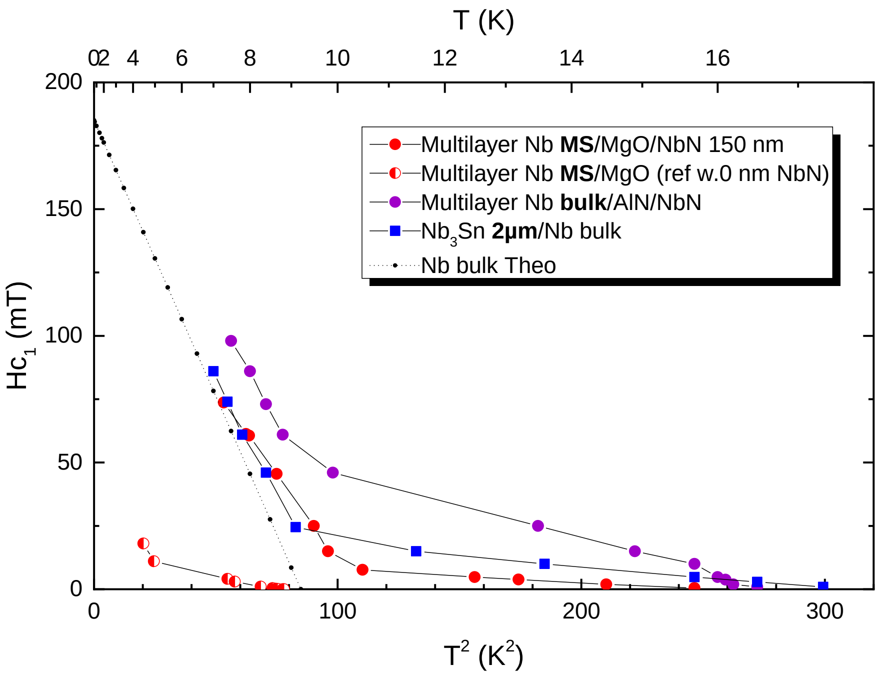
Magnetometry system at CEA

- **Principle**: measure critical penetration fields (without vortex) and predict **Eacc**
  External field applied with coil << sample size => similar to cavity configuration
  Measure the vortex nucleation *(trapped, they introduce non linearity in the measurement)*
- **Measure** trapped vortices (point defects)



Magnetometry system at CEA

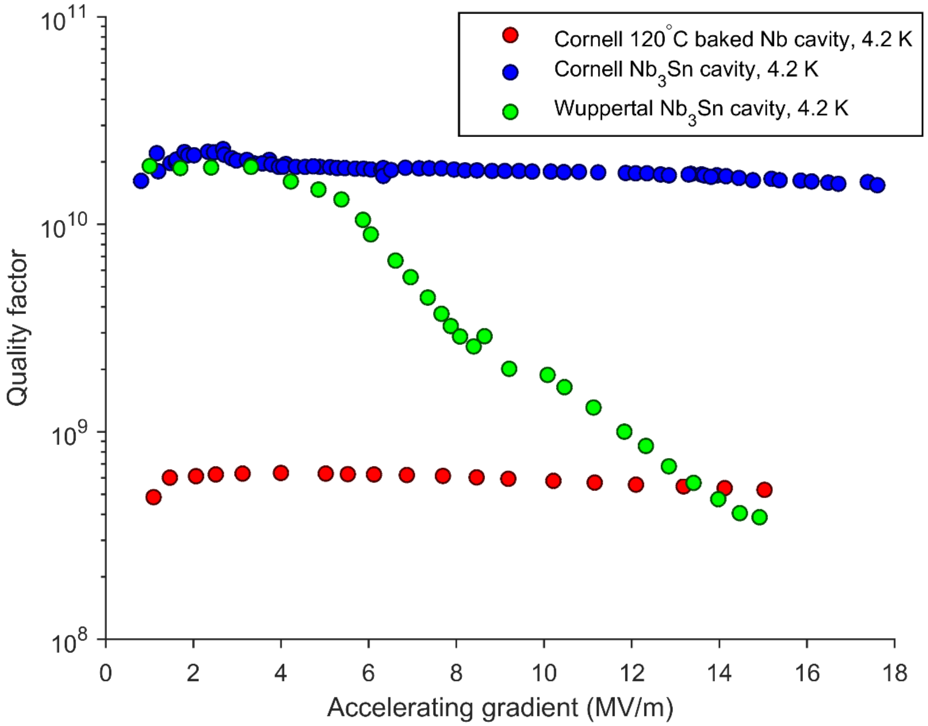


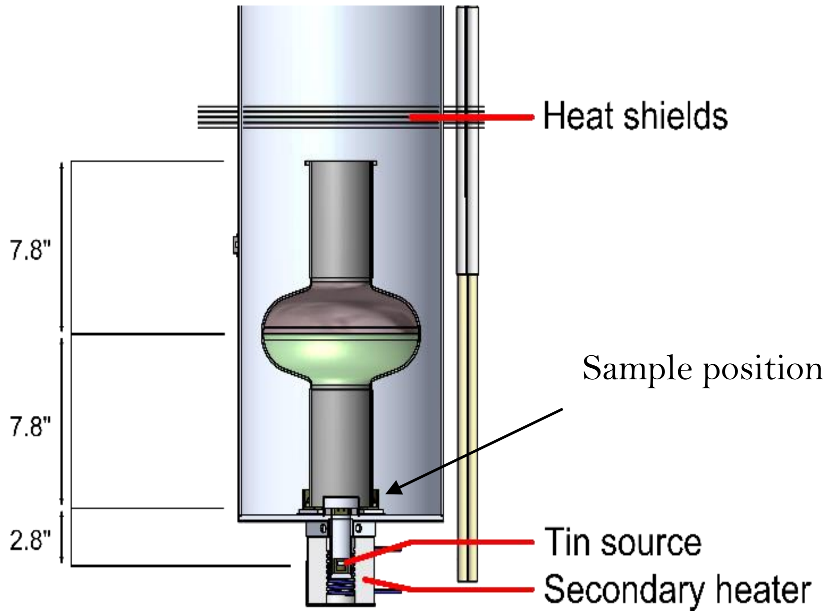


- Measured samples:
  - Thin films on Nb : Magnetron sputtered, HPIMS, ALD….
  - Nb_3Sn (collab Cornell)
  - Damaged layer (starting)
  - Multilayers on thin Nb films or bulk Nb

- Temp: from 4,2 to 300K
- External magnetic field: up to 130 mT
- Sample size: Ø ≥ 30 mm

Nb_3Sn/Nb (Cornell-FNAL)

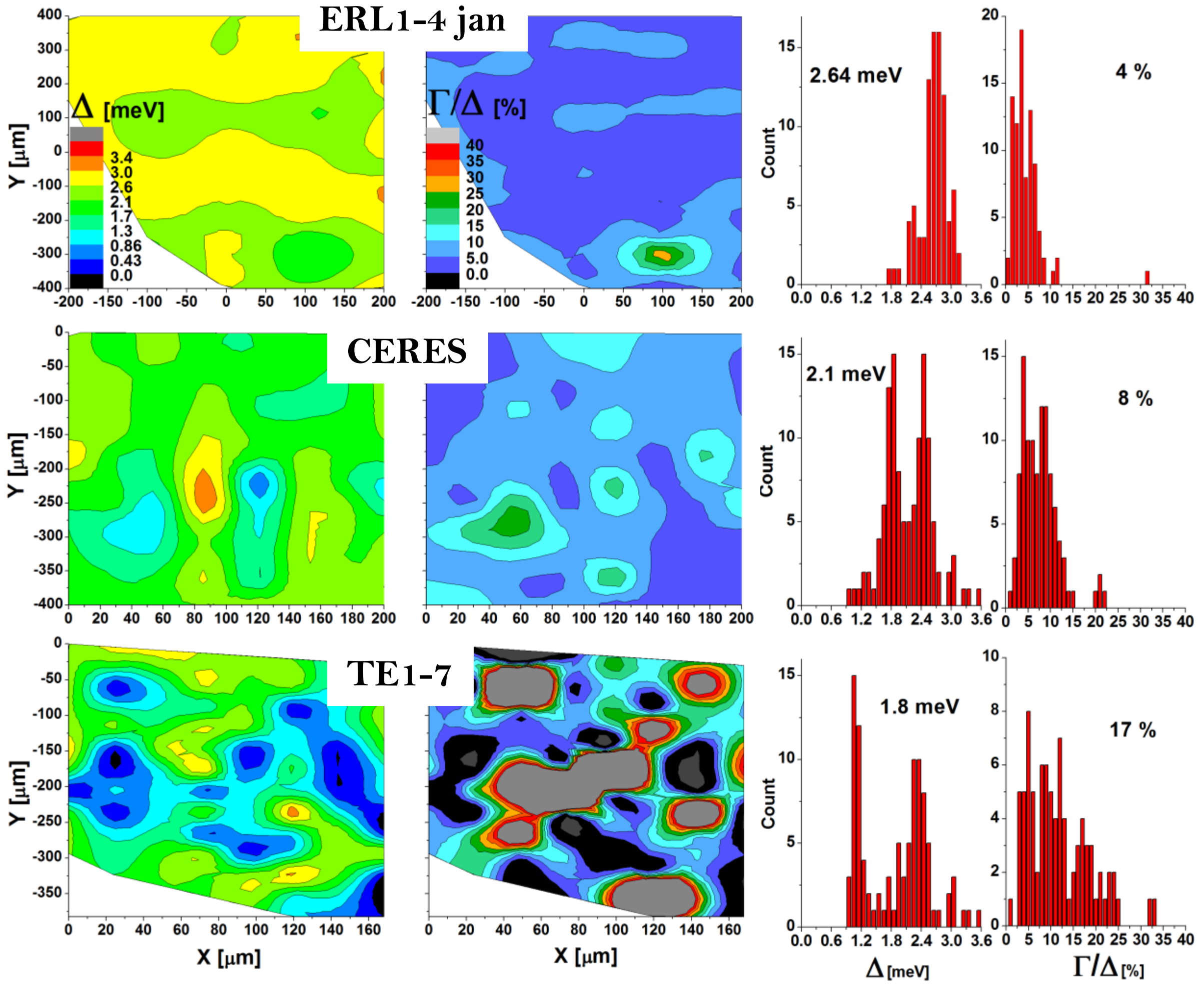




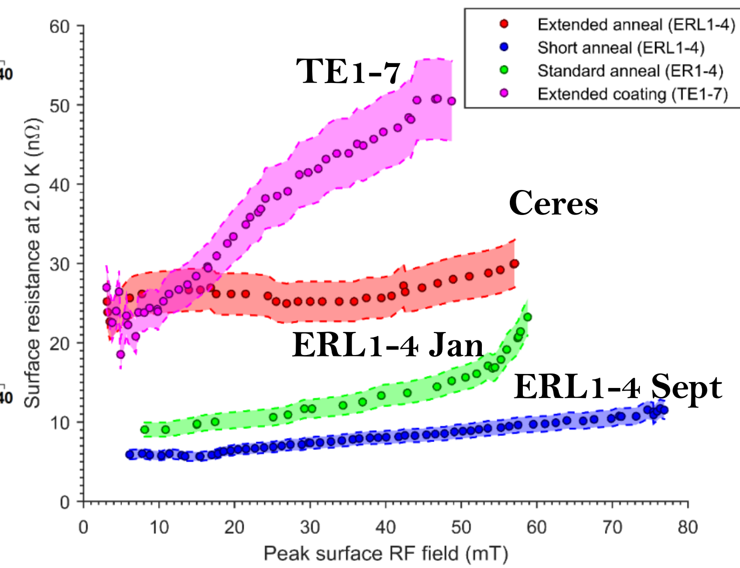
- Wupperthal method: diffusion of Sn in a Nb cavity
- Nb_3Sn Q_0 at 4,2K ~ Nb Q_0 at 2K
- Moderate increase of Q_0 between 4K to 2K -> Non-BCS
- Q_0 decrease at ~ 6K

Have we reached the limits of Nb_3Sn ?

Nb_3Sn/Nb (Cornell) - PCT



Nb3Sn cavity RF tests



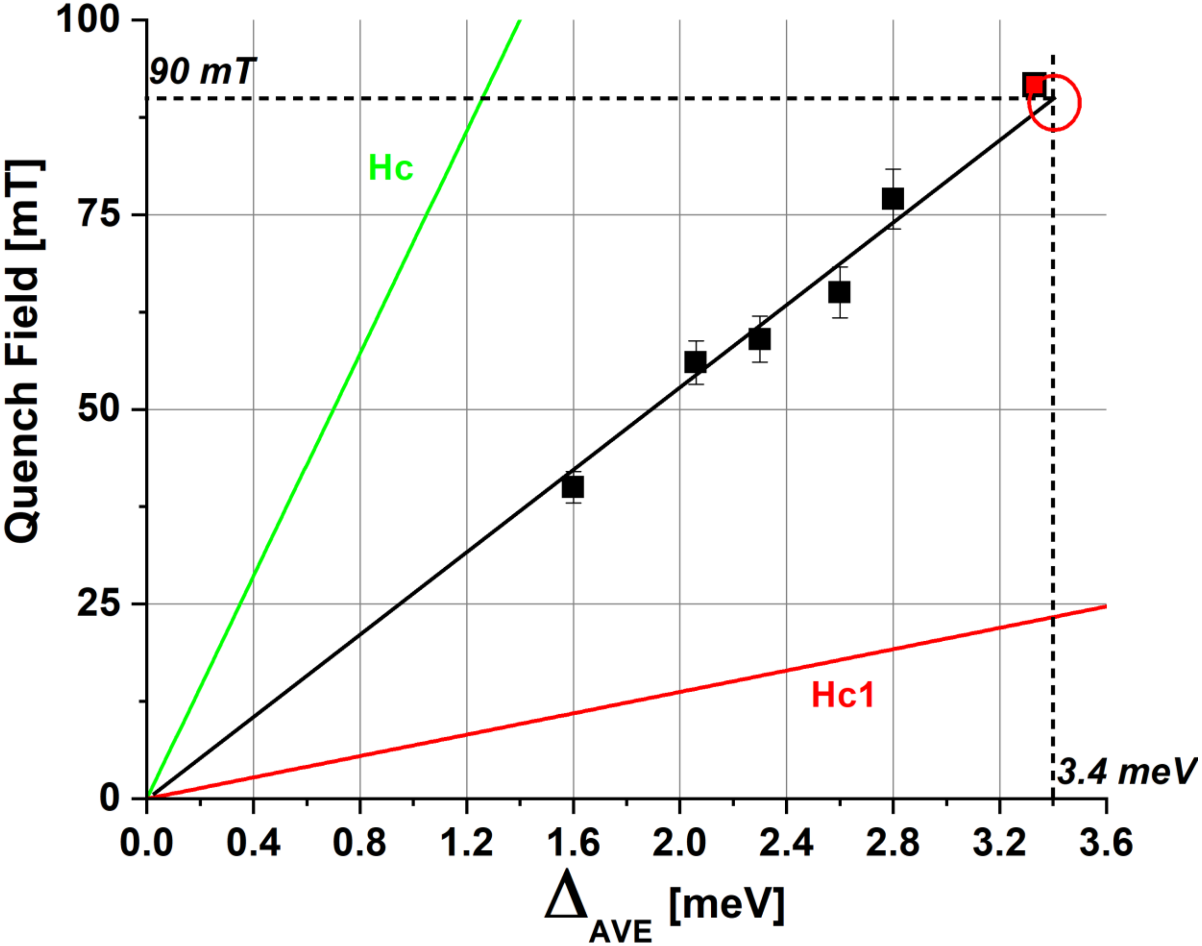
- Δ > Nb and Γ/ Δ is small

-> Quality factor @ 4K is ~ Nb @ 2K

- But pockets of Nb rich phases:

- Lower Tc and Δ
- Carbon contamination

Nb_3Sn/Nb (Cornell - FNAL) – PCT



For large κ (=λ/ξ = 24) :

$$H_{C1} = \frac{1}{\sqrt{2}\kappa}(Ln[\kappa] + 0.08)\,H_C$$

$$H_C = \sqrt{\frac{N_0}{\mu_0}}.\Delta.e$$

$N_0 = 2.5\ 10^{35}\ e^- / spin / m^3$

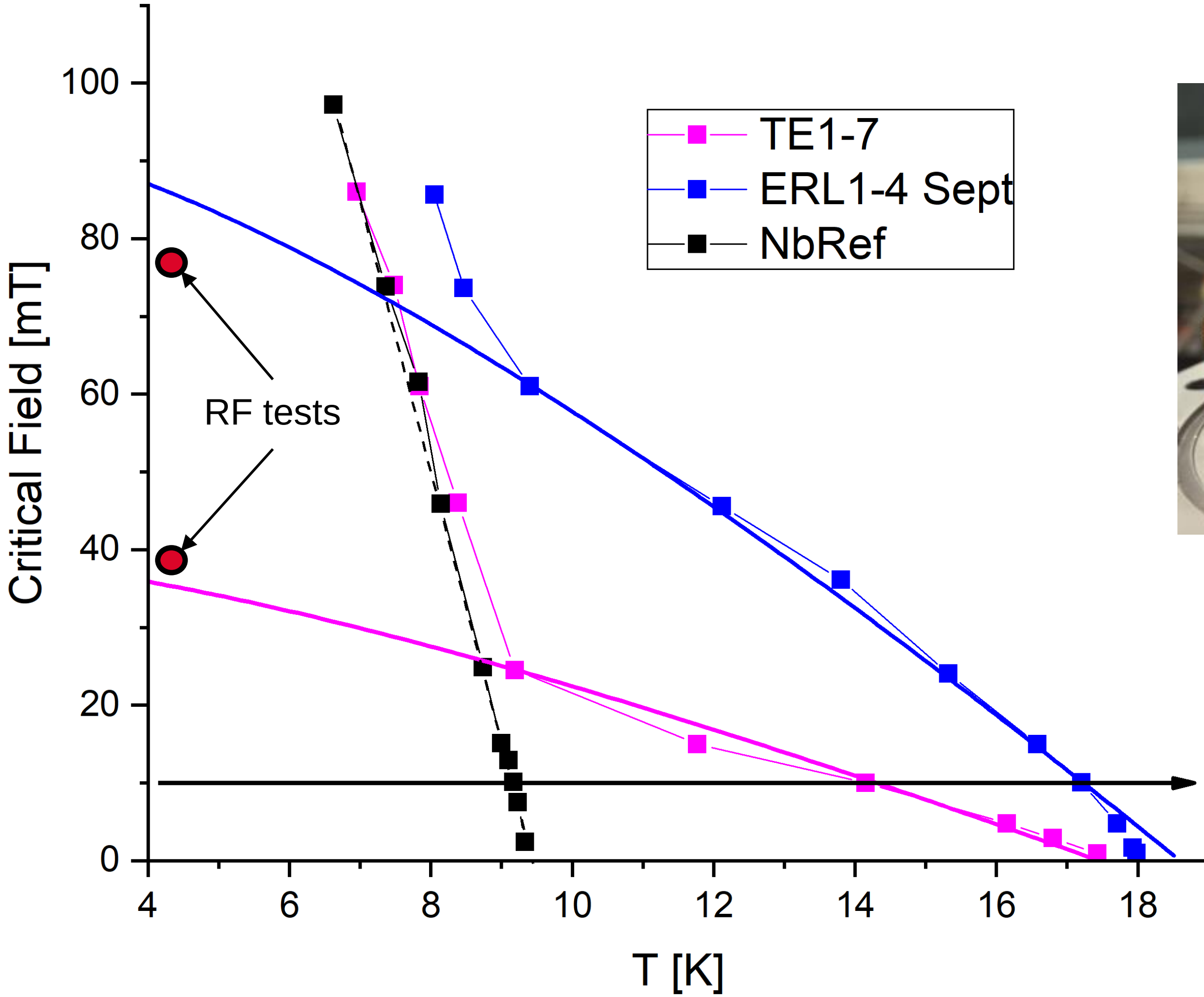
$$H_{SH} = 26\ \pm 2.5\,\Delta\ mT/meV$$

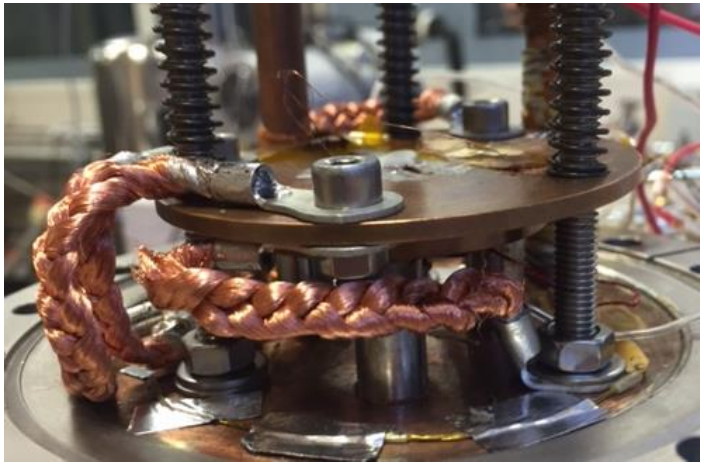
Bulk Δ for Nb_3Sn is 3.4 to 3.5 meV

-> Max expected Quench field is ~ 91 ± 2 mT = 22 MV/m

- A15 compounds (V_3Si, Nb_3Sn, Nb_3Al…) are good for Q_0 and higher operation temp. (4,2 K)

Nb_3Sn/Nb (Cornell) - Magnetometry





- Measure critical penetration field in Bulk and thin films samples
- Sample size: > 1 inch
- 4.2 K and 120 mT

- ➢ The critical field measured by Magnetometry correlates with RF tests Quench fields
- ➢ But what about E_{MAX} ? How to increase E_{MAX} ?

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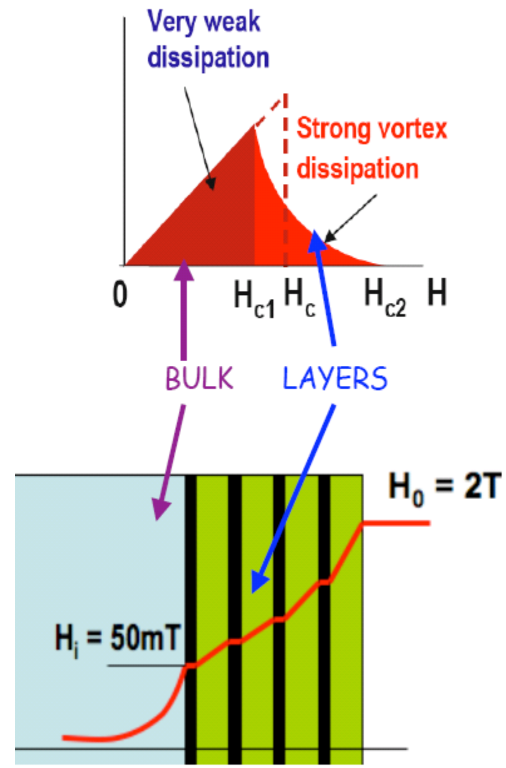
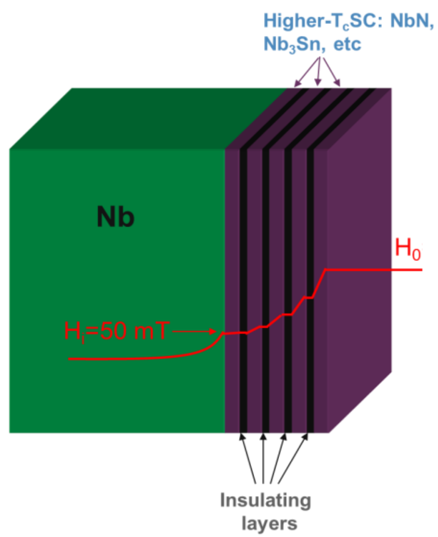
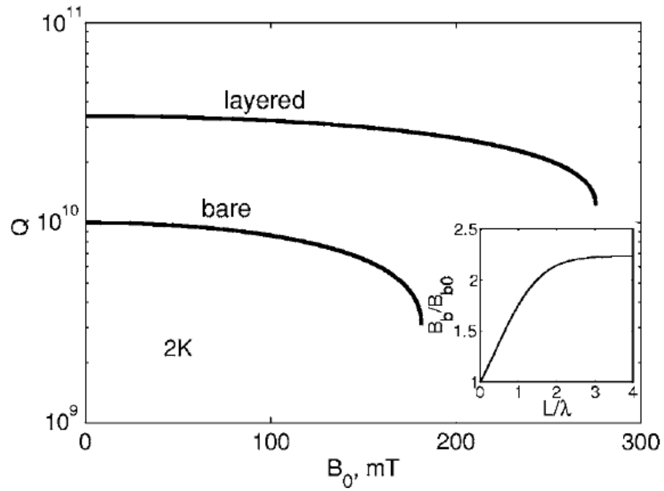
Fields in bulk Nb cavities approaching dc depairing limit for Nb, $H_c(0) \approx 200$ mT

Superconductor-Insulator multilayer [Gurevich, *Appl. Phys. Lett.* **88**

- Increase performance
  - Move beyond limits of Nb
- Decrease cost
  - Higher operating temperature (reduce cryogen costs)
  - Replace bulk Nb with cheaper material (Cu/Al)





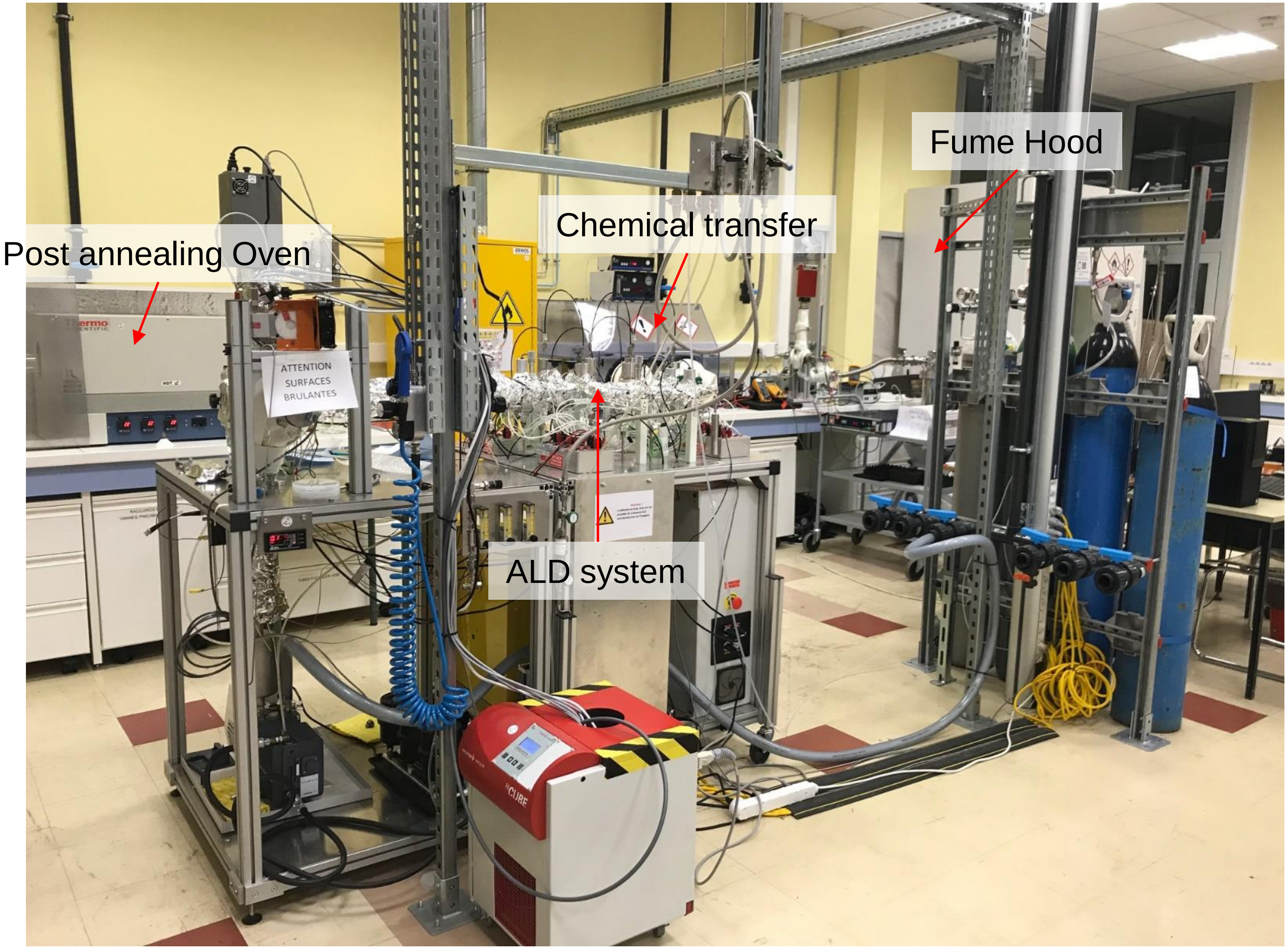


A. Gurevich, APL 88, 012511

$$B_{c1} = \frac{2\phi_0}{\pi d^2} \ln \frac{d}{\tilde{\xi}}, \quad d < \lambda,$$

- Coat inside Nb SRF cavity with precise, layered structure → ALD

Set up of the ALD laboratory

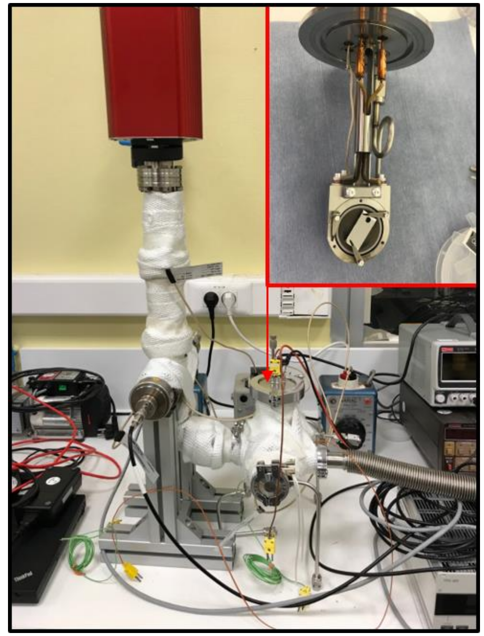


- 7 chemical precursors
- Temperature up to 500°C
- RGA and QCM in-situ monitoring
- Design to fit 3 and 1,3 GHz cavities
- Fully automated
- Deposition homogeneity < 1%

Thin films developements at CEA

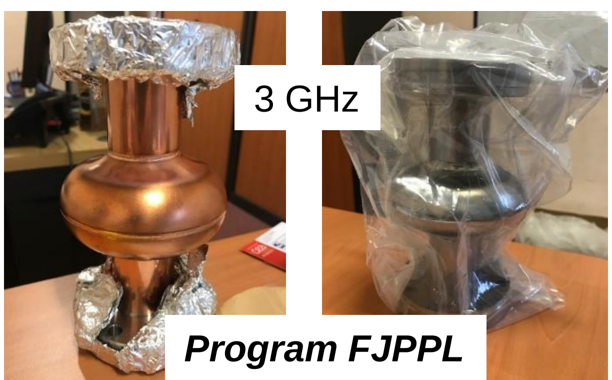
- Deposition on BCP, EP bulk Nb samples + Post annealing treatment in High Vacuum

Annealing



- Up 1000°C
- 1 inch samples
- 5.10^{-6} mbar at 800°C
- RGA and gaz feedthroughs
- Set for Insitu X-ray studies

- Soon on 3GHz and 1,3 GHz cavities



Annealing

- Up 1000°C
- Up 1,3 GHz cavities
- 10^{-6} mbar at 800°C
- RGA and gaz feedthourghs

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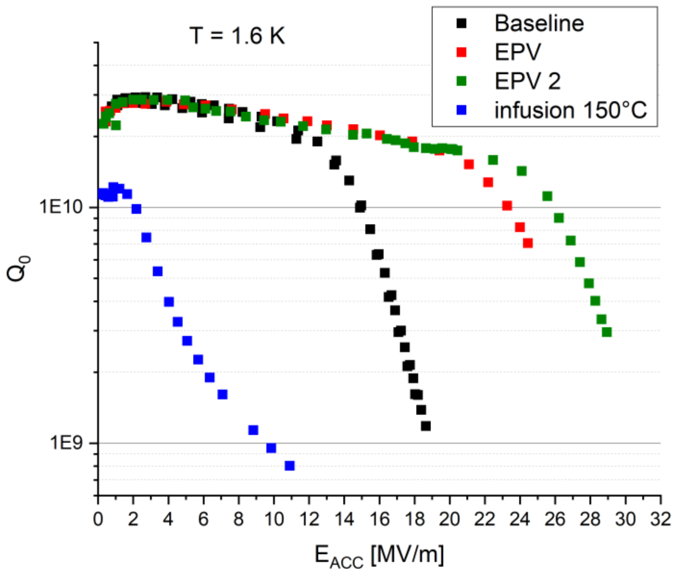
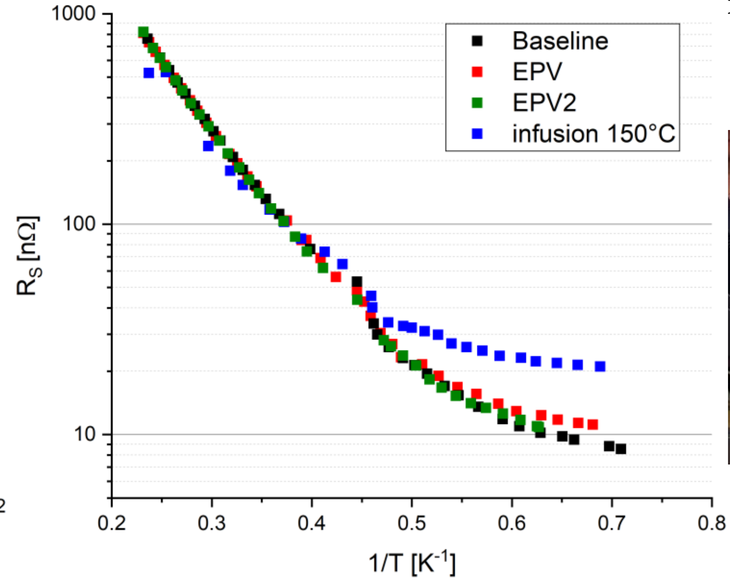
Bulk Nb Infusion – (IPNO/CEA)

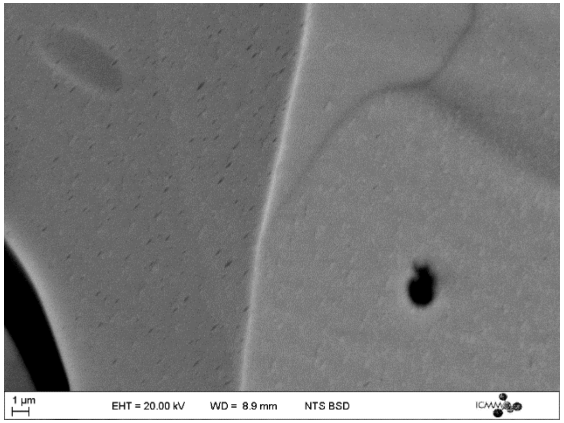
- Diffusion of N in the first nm's of bulk Nb cavities.

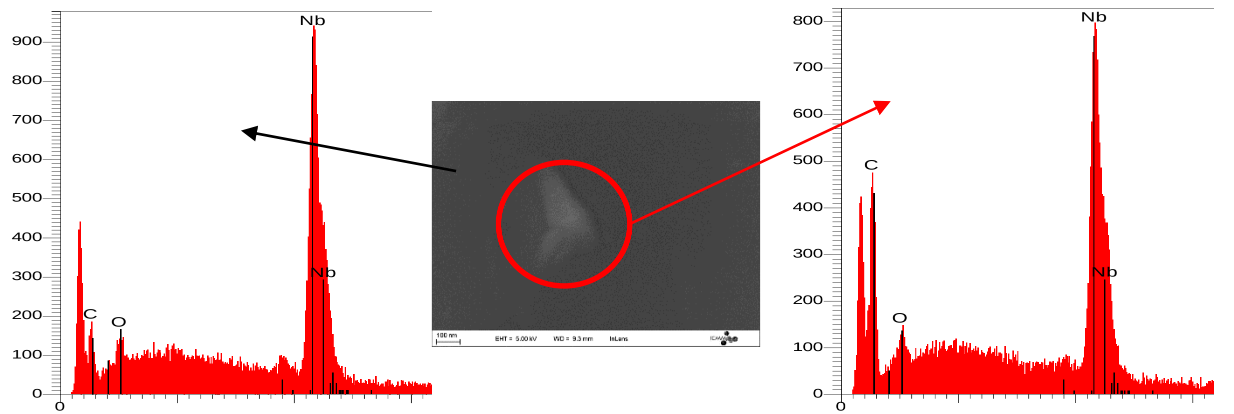




ʾrocess: 150°C – 48hr under 0,025 mbar N_2

- Treated Samples





- Carbon pollution -> improve process

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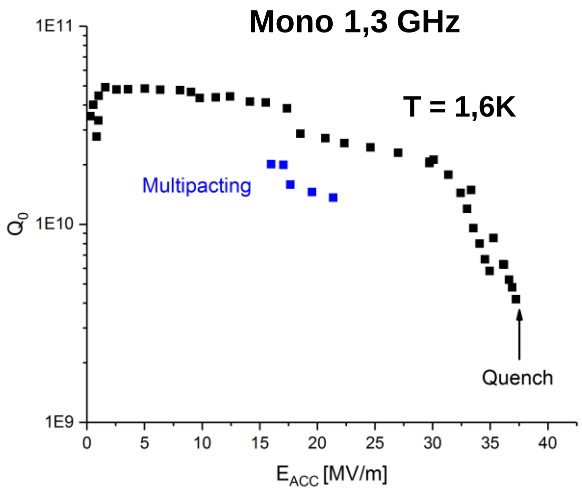
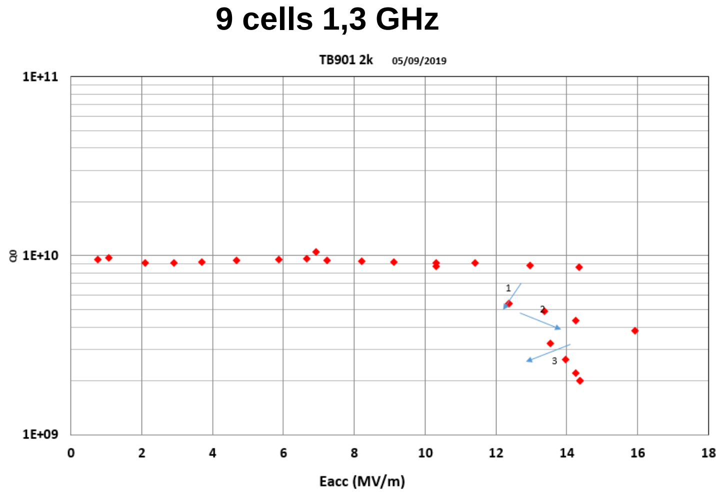
Chemistry: Vertical electropolishing

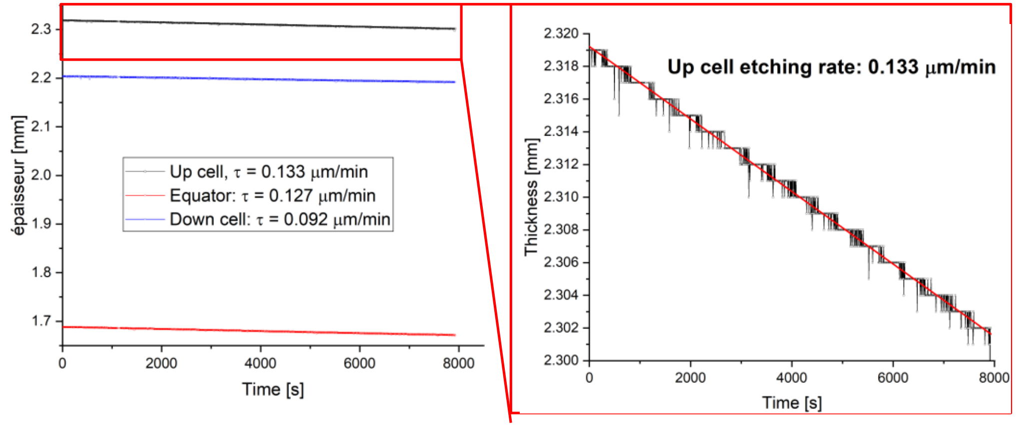
Program FJPPL: collaboration KEK + marui

- Vertical Electropolishing mono cell 1,3 GHz cavity: 37,5 MV/m without baking
- Vertical Electropolishing 9 cell 1,3 GHz cavity: On Going…





- Future: EPV on 704MHz cavity
- Real time multiple point thickness measurements during chemistry



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- ‘Cobot’-ization

Robotization

Robotization should reduced assembly mistakes

Robotization could be implemented for, e.g. in order of complexity:

- Ionized N2 cleaning,
- Coupler assembly,
- String assembly,

Robotization will be beneficial with respect to :

- Reducing labour cost
- Uniformization of assembly procedures across several regional assembly plants
- Introducing 'plug-compatible' component design variations

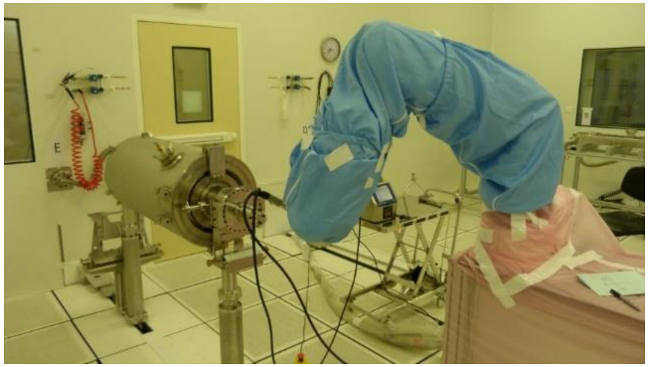
'Cobot'-ization

A first 'proof of principle' experiment has been implemented at Saclay, in the Eu-XFEL/ESS Clean Room with a 'collaborative' robot, a.k.a 'Cobot', for the Ionized-N2 cleaning of the blind holes ESS cavity flange .

CEA proposal to Japan-France collaboration

- With the experience gained on the assembly of the cryomodules at European-XFEL, CEA-Saclay is pursuing R&D effort on robotization.

Cobot



Cobot in Saclay ISO4 Clean Room

R&D plan (KEK/ CEA-Saclay)
JFY2020: (KEK) Robot introduction for dust removal of electrostatic remover
(CEA) Cobot tests for cleaning all flanges of one cavity
(CEA) Evaluation of cobot for flange assembly
JFY2021: (KEK) Development of robot operation program, learning of operation work
(CEA) Order Cobot and development of the flanges assembly by robot
JFY2022: (KEK) Operation confirmation by robotization of equipment
(CEA) Operation confirmation by robotization of equipment

Summary

Characterization:

- Two unique set of characterization tools with predict power for RF cavity tests
  - ➢ Enable testing recipes/surface treatments/heterostructure on coupons prior to cavity tests
  - ➢ Faster turner over and phase space exploration of growth parameters etc…

Thin film growth:

- Set up ready to deposit on coupons, 3 and 1,3 GHz cavities

➢ Study influence on RF properties of heterostructures made by ALD

➢ Post annealing capalities for samples and cavities

Vertical Electropolishing:

➢ Very good results on 1,3 GHz monocell cavities

➢ On Going optimization effort on 9 cells and 704 MHz cavities

Thanks you

The END