DE LA RECHERCHE À L'INDUSTRIE

# Correlations between Tunneling Spectroscopy and SRF cavity perfomances

**Thomas Proslier**

TTC – CERN - 05/02/220

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TRIUMPH: T. Junginger (characterization)

**Cornell: D. Hall, M. Liepe ($Nb_3Sn$)**

## Correlations between Tunneling Spectroscopy and SRF cavity perfomances

- Point Contact Tunneling spectroscopy
- Bulk Nb treatments
- $Nb_3Sn$/Nb
- Summary and future

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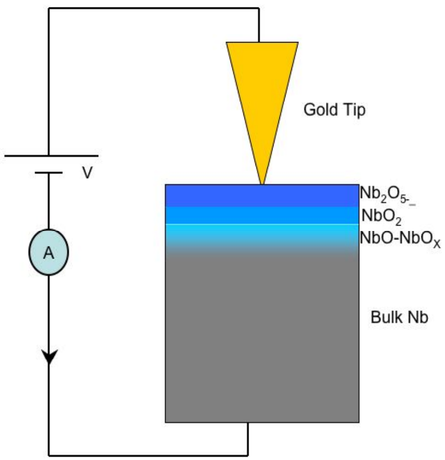
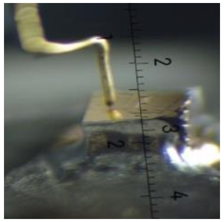
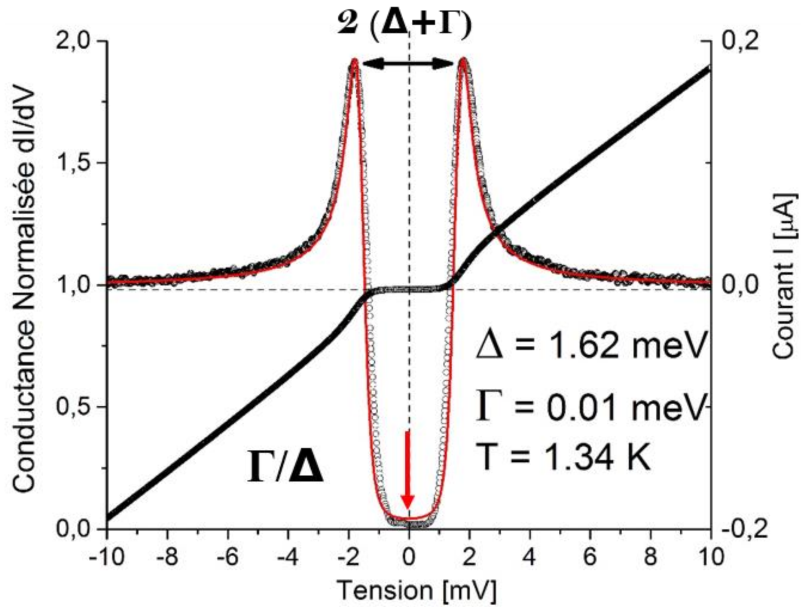
# Tunneling spectroscopy: what do we measure and why?

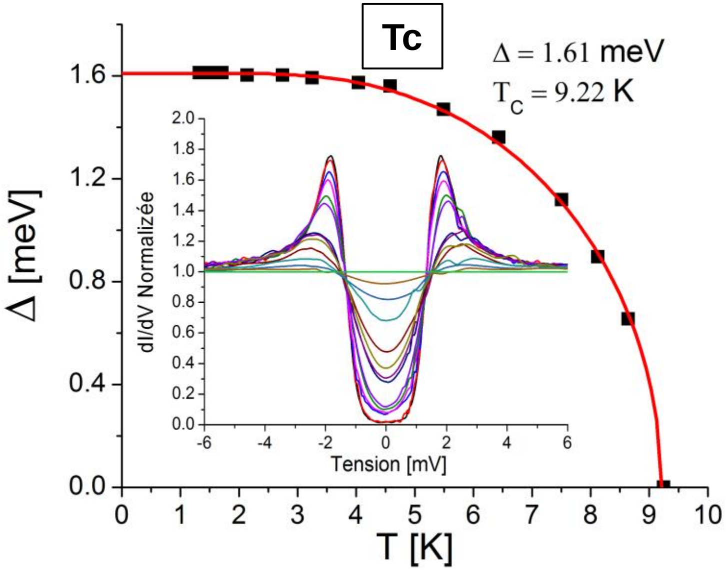
## principle



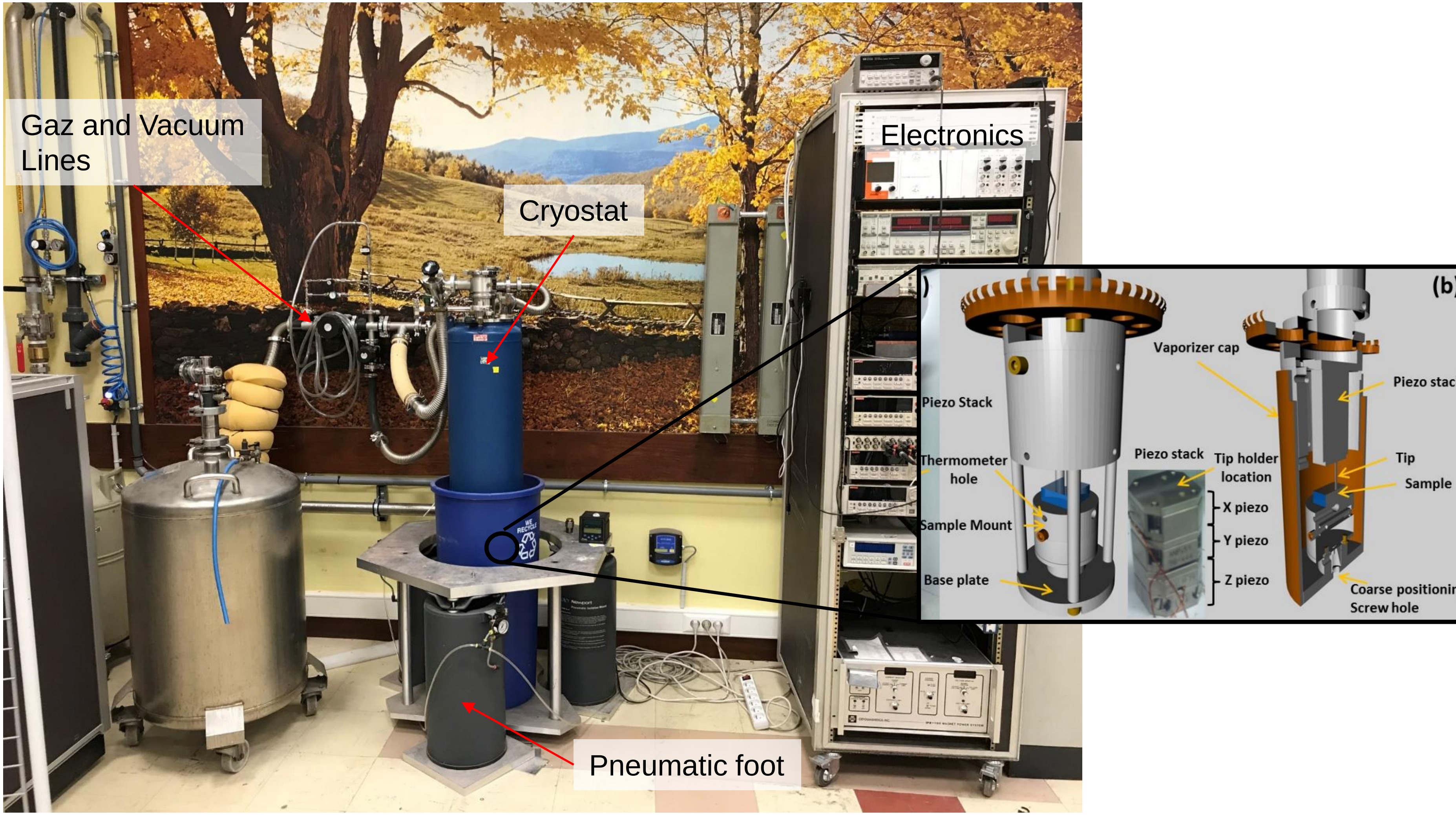
## measure




- Measure the fundamental superconducting parameters: $\Delta$, $T_C$, $H_{C2}$
- Measure non-ideal signature: Γ.
- Shape of the DOS give clues to microscopic origins: *Proximity effect, magnetic impurties, deleterious phases*.
- Direct correlation to SRF cavity performances.
- Cartography.

# The Point Contact system at CEA




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

*Used for Nb/Cu, bulk Nb doping, Nb3Sn, mutlilayers etc…*

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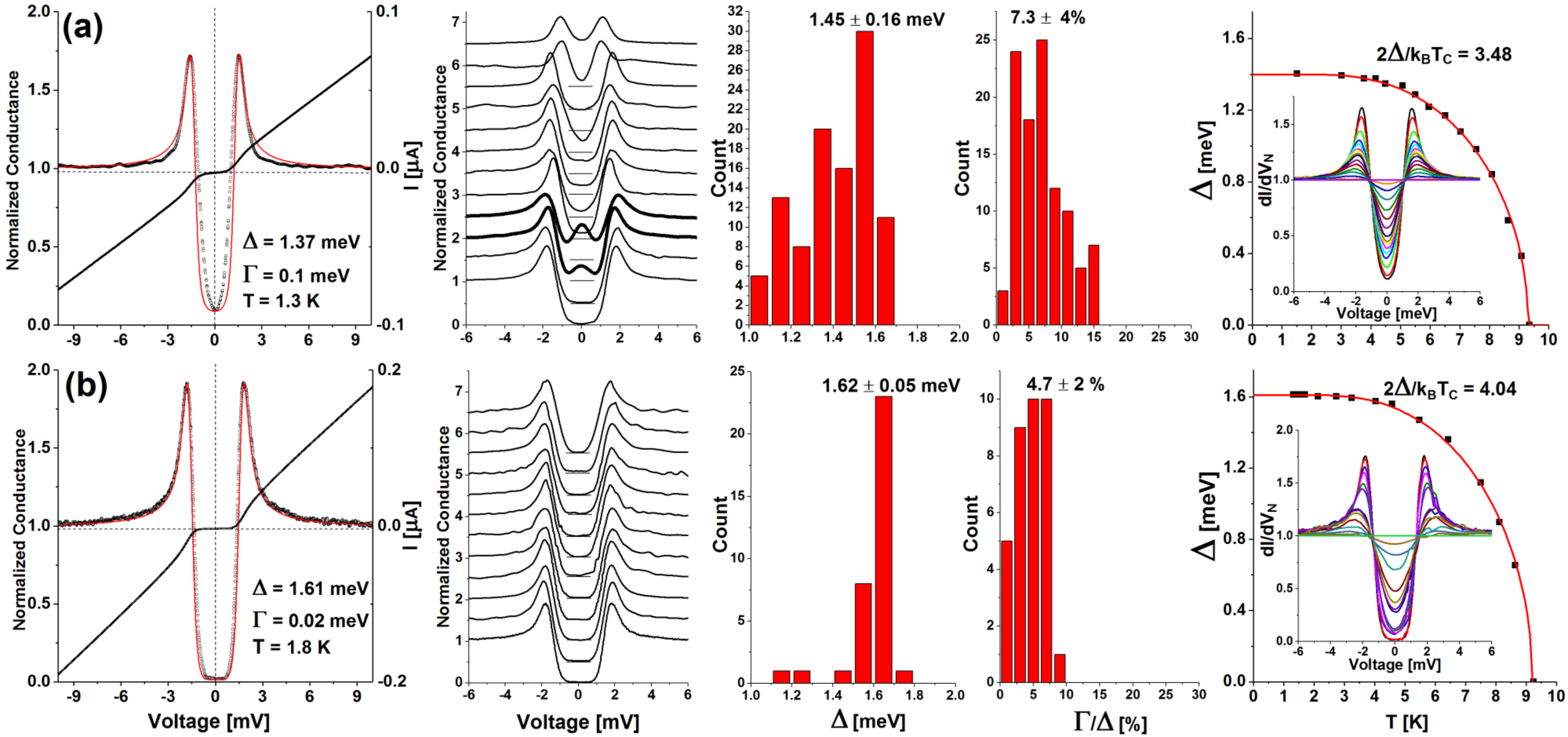
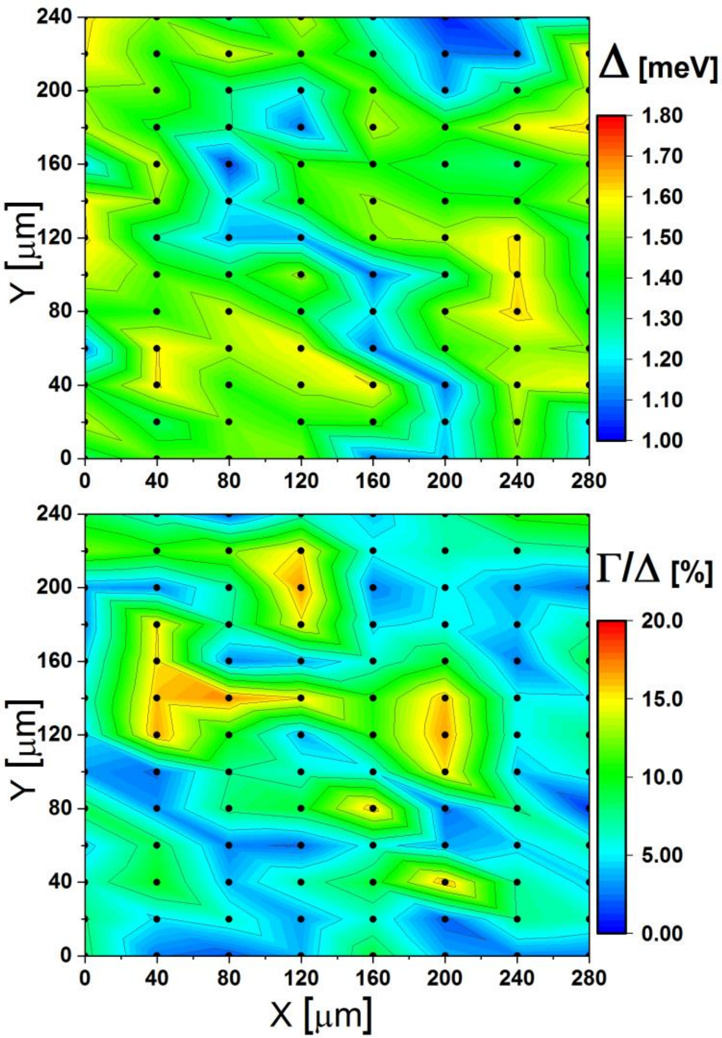
# Tunneling spectroscopy: Bulk Nb HFQS



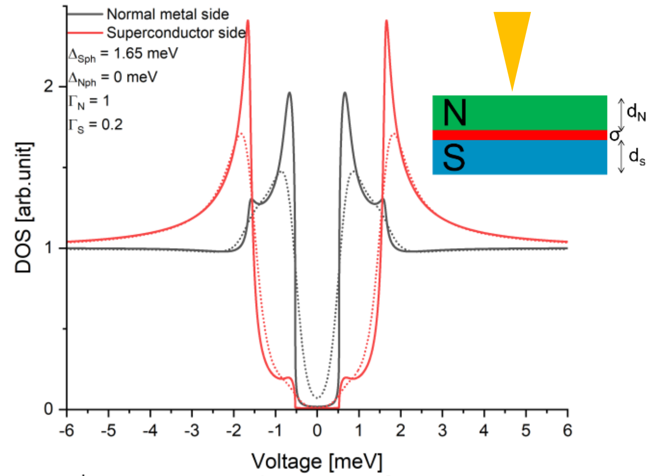

- Hot Spots:
- spread of gap values as low as 1 meV
- Inelastic scattering parameters Γ
- Zero Bias Peaks

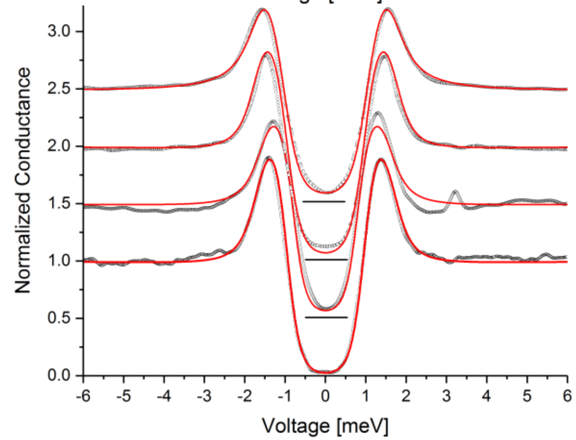
- Cold Spots:
- Narrow gap distibution 1.6 meV
- Lower Inelastic scattering parameters Γ
- No zero bias peaks

# Tunneling spectroscopy: bulk Nb - Why small gaps?




- Proximity effects: MacMillan Model




- ○ Any Temperature.
- ○ Diffusive scattering
- ○ Low transparency interface (σ=0.1).
- ○ No spatial dependence

- ○ $\Gamma_S$, $\Gamma_N$, $\Delta_{Sph}$ , $\Delta_{Nph}$

$\Gamma_{N/S} = \hbar . V_{FN/S} . \sigma / (2.B.d_{N/S})$

- ○ Distinguish btw buried and surface normal metal phases

$\Gamma_S << \Gamma_N \rightarrow d_N << d_S$

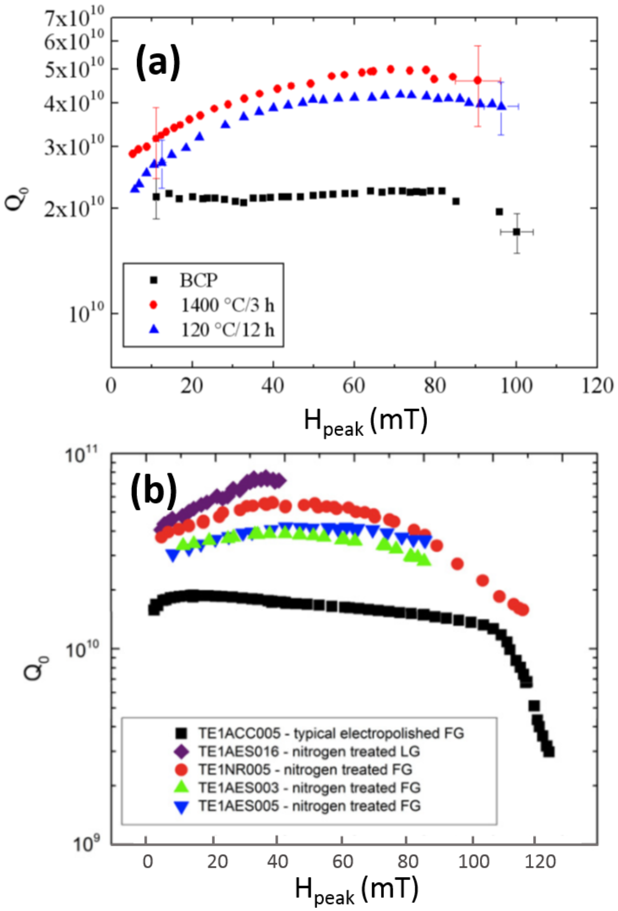
$\Delta_{Sph}$ (1.6 meV) , $\Delta_{Nph}$ (0 meV)

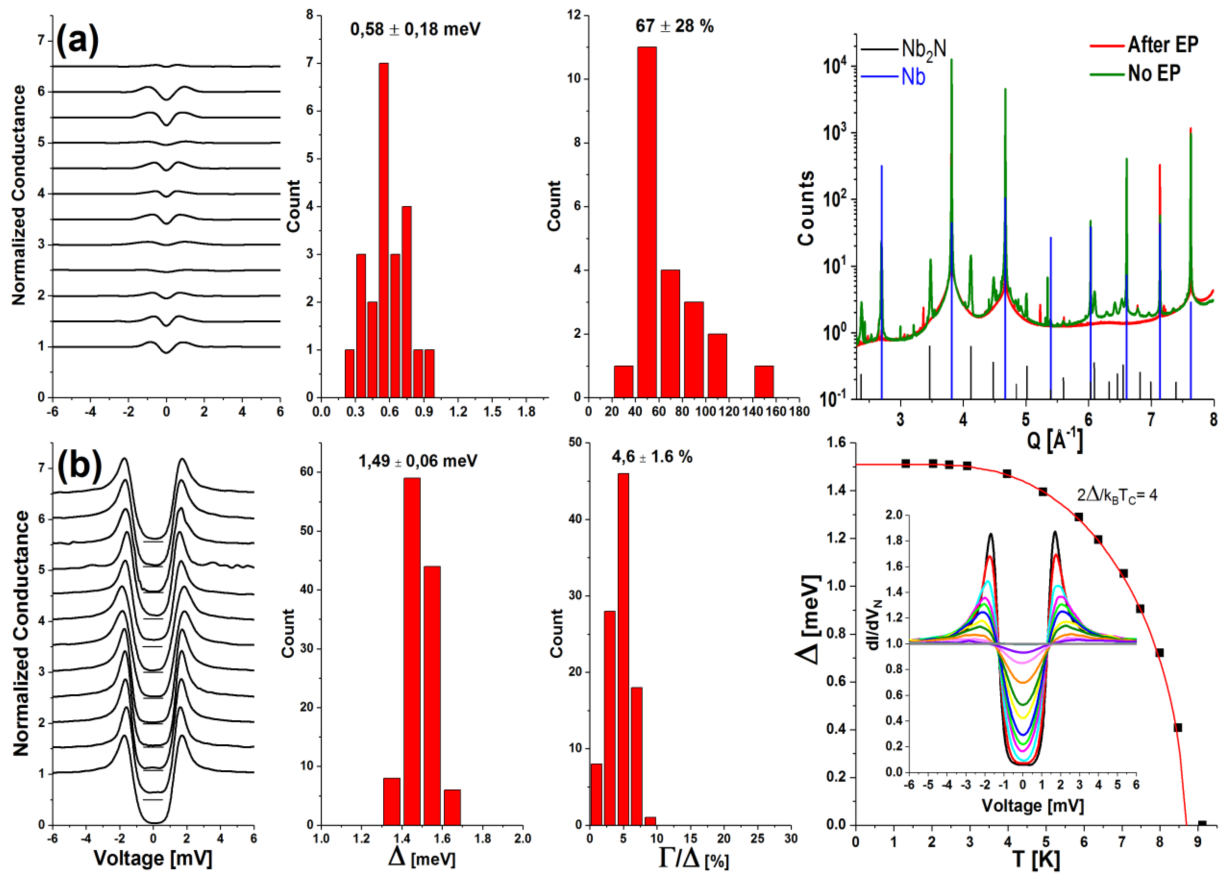
- ***Presence of normal metal regions:*** 10 nm < $d_N$ < 15 nm -> reduce the quench field of SRF cavities: $H_B \sim \Phi_0 / (6\ \lambda_N\ d_N)$ Onset at 100 mT -> $d_N \leq 20$ nm consistent with PTC.

Transparent at low fields (Q0) but revealed at « higher » accelerating gradients.

- Candidates: Nb Hydride phases at the surface (XRD at 90 K no sign of $NbH_X$ phases)

# Tunneling spectroscopy: Nb Doping: N and Ti



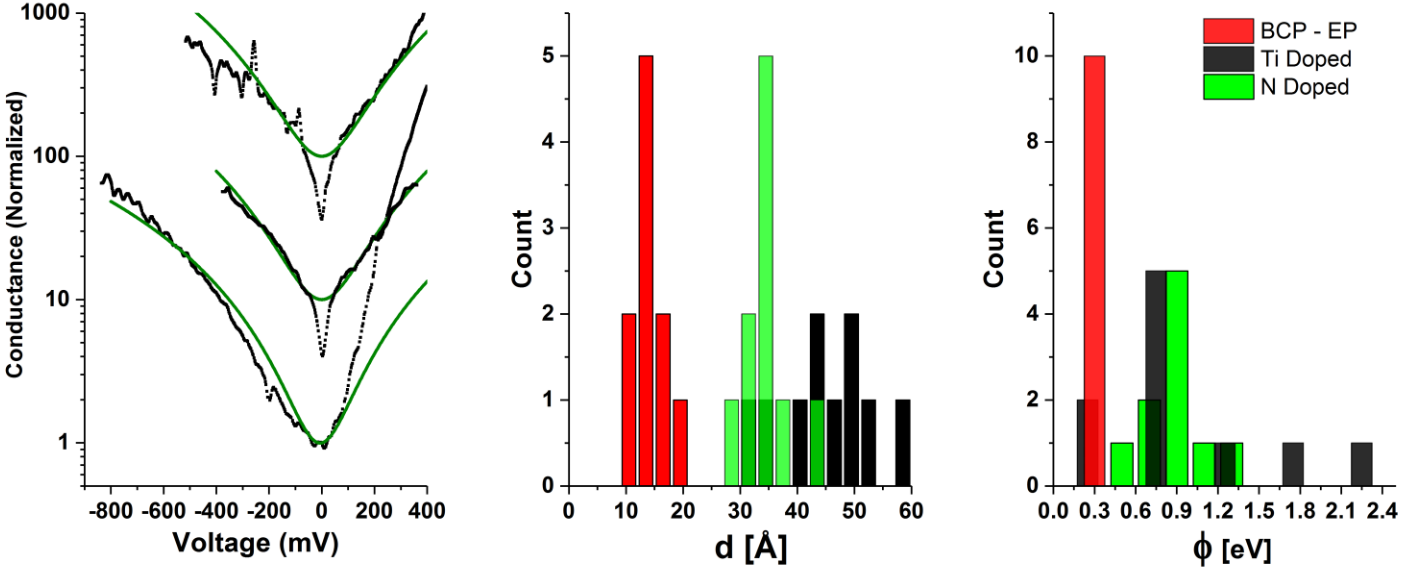




- **N / Ti Doping:**
  - Narrow gap distribution
  - Very low Inelastic scattering Γ values
  - Near ideal DOS
  - No Zero Bias Peaks

- **But:**
  - Gap values a bit lower (1.48 meV) than bulk Nb (1.6 meV)
  - Tc (8.7 K) < Bulk Nb Tc (9.2)
  - Ratio 2Δ/kTc = 4 (similar to this cavity)

# Tunneling spectroscopy: Nb

## High Bias region




$$\frac{G(V)}{G(0)} = 1 - \left(\frac{A_0 \Delta\varphi}{16\bar{\varphi}^{3/2}}\right) eV + \left(\frac{9}{128}\frac{A_0^2}{\bar{\varphi}}\right)(eV)^2$$

d, thickness of the oxide
Φ, work function of the oxide
$\Phi_{TIP}$, work function of the tip

- Undoped: reduced barrier height and thickness
- Doped (Ti or N): higher barrier height and thickness

Points towards defects in the oxide mitigated by addition of dopants:

- TLS – Hydrogen relationship and ZBP as signature
- *Qbits : magnetic impurities, H + O(?) as a source of it*
- *Low fields measurements*

## Correlations between Tunneling Spectroscopy and SRF cavity perfomances

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- $Nb_3Sn$/Nb
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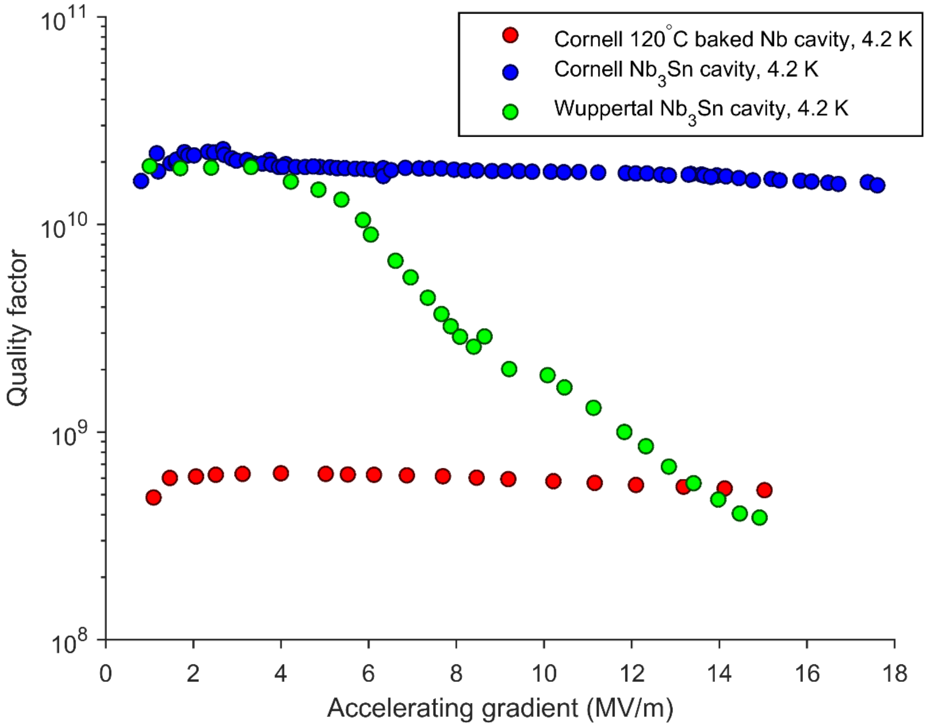
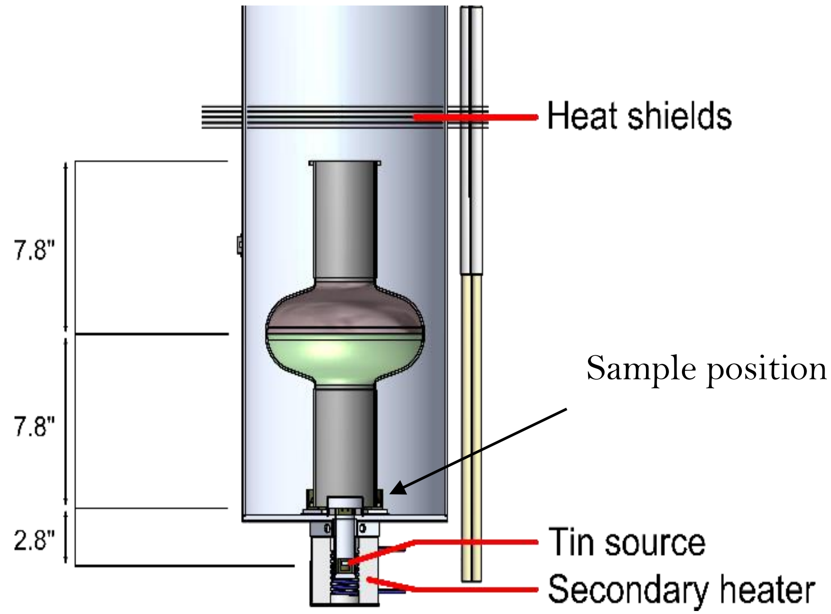
# $Nb_3Sn$/Nb (Cornell)



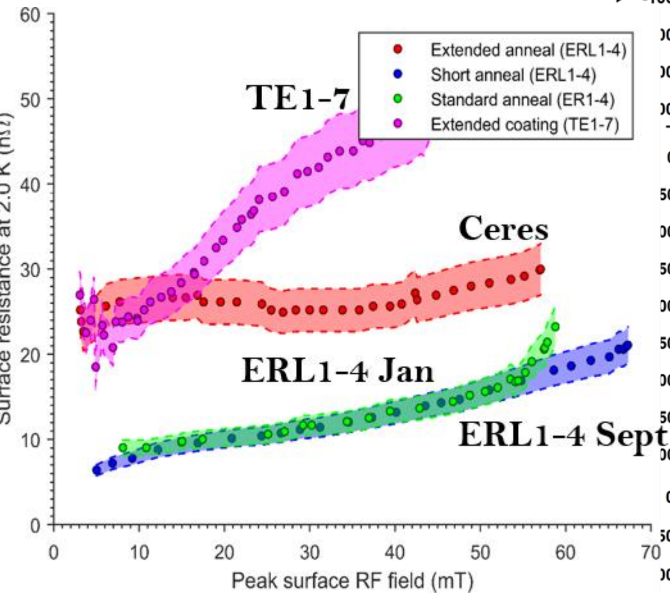




- Wupperthal method: diffusion of Sn in a Nb cavity
- $Nb_3Sn$ $Q_0$ at 4,2K ~ Nb $Q_0$ at 2K
- Moderate increase of $Q_0$ between 4K to 2K -> Non-BCS
- $Q_0$ decrease at ~ 6K

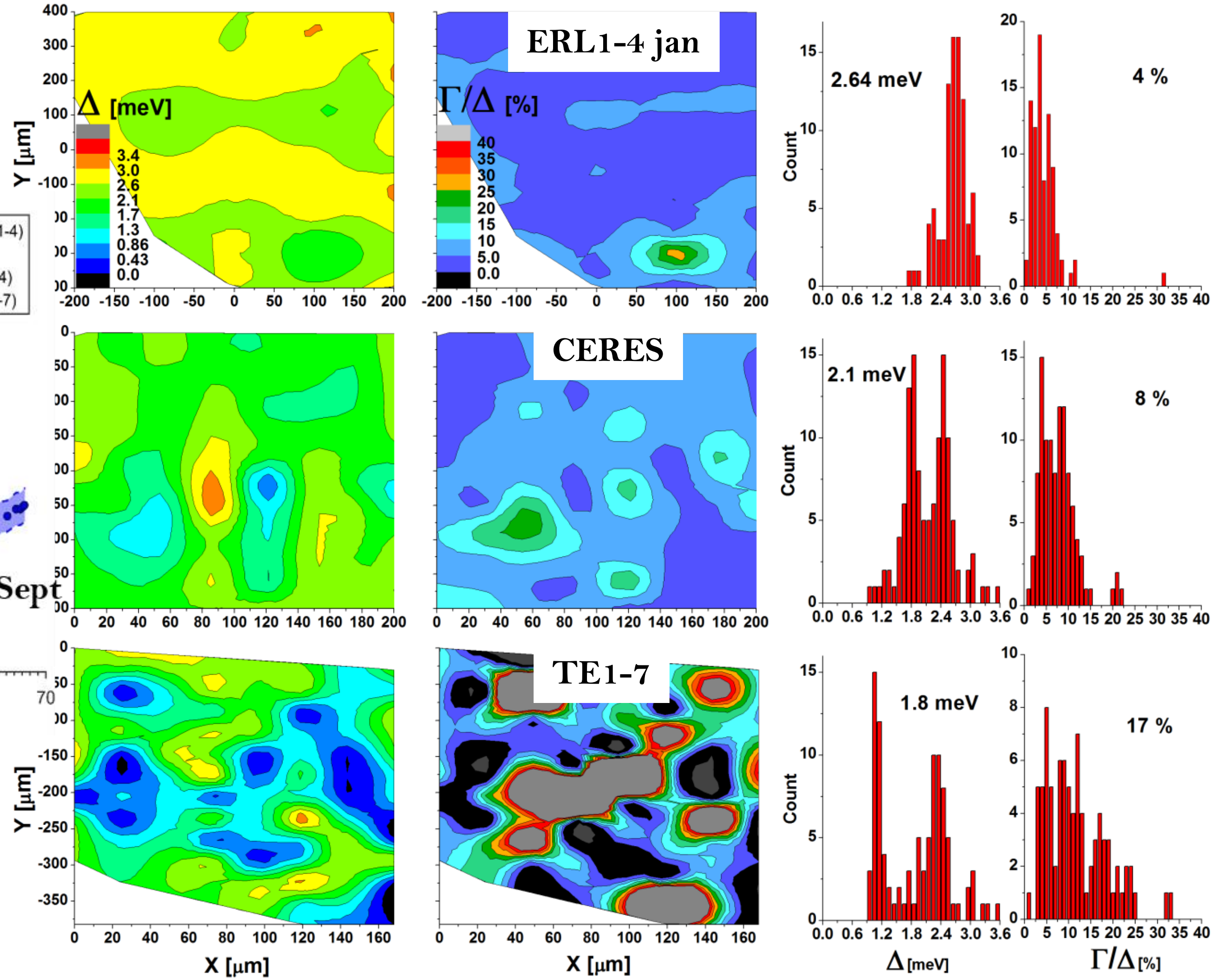
Have we reached the limits of $Nb_3Sn$ ?

# $Nb_3Sn$/Nb (Cornell) - PCT

## Nb3Sn cavity RF tests




## PCTS measurements



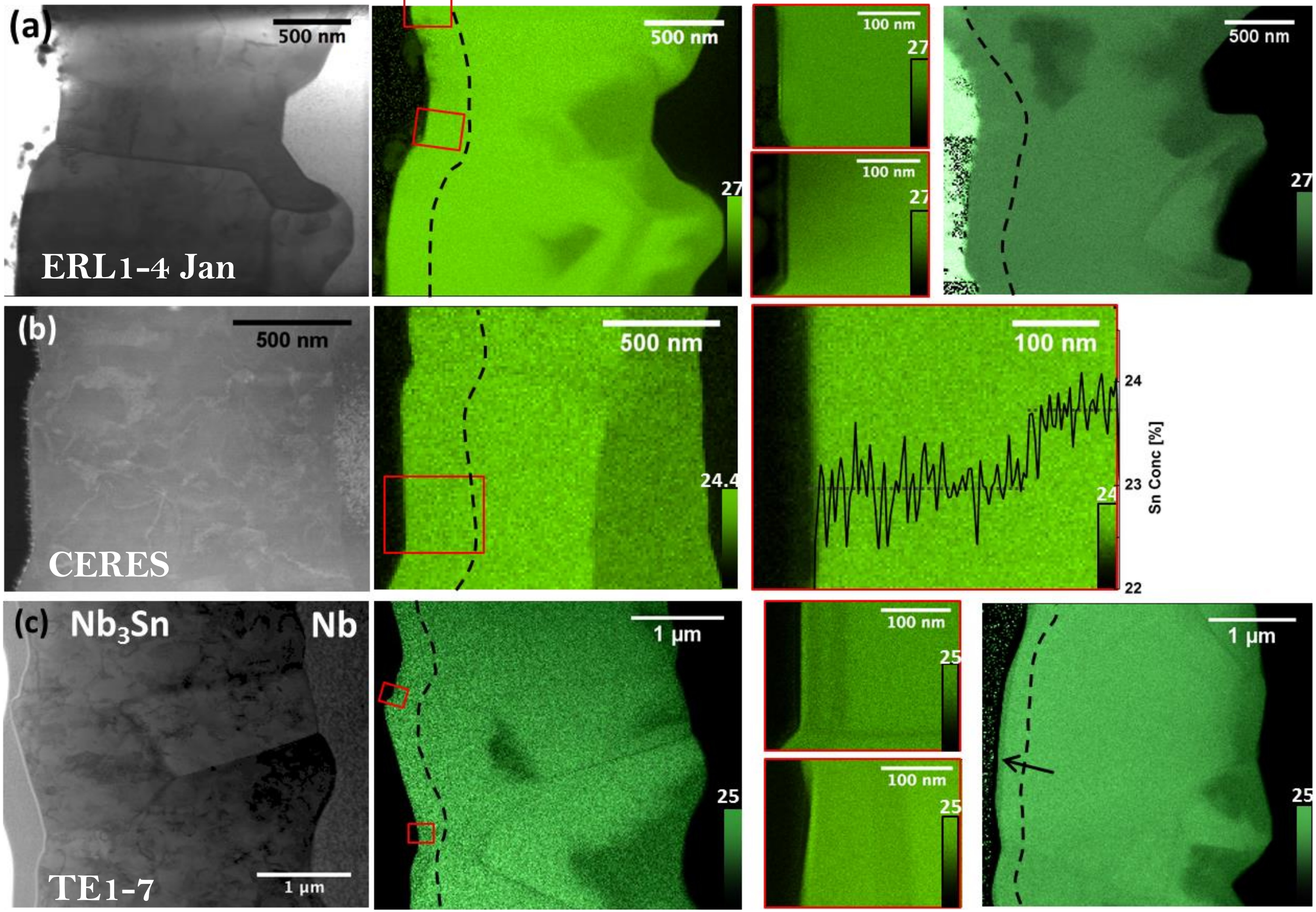

- Δ > Nb and Γ/ Δ is small

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

- But pockets of Nb rich phases:

- Lower Tc and Δ
- Carbon contamination

# $Nb_3Sn$/Nb (Cornell) – TEM

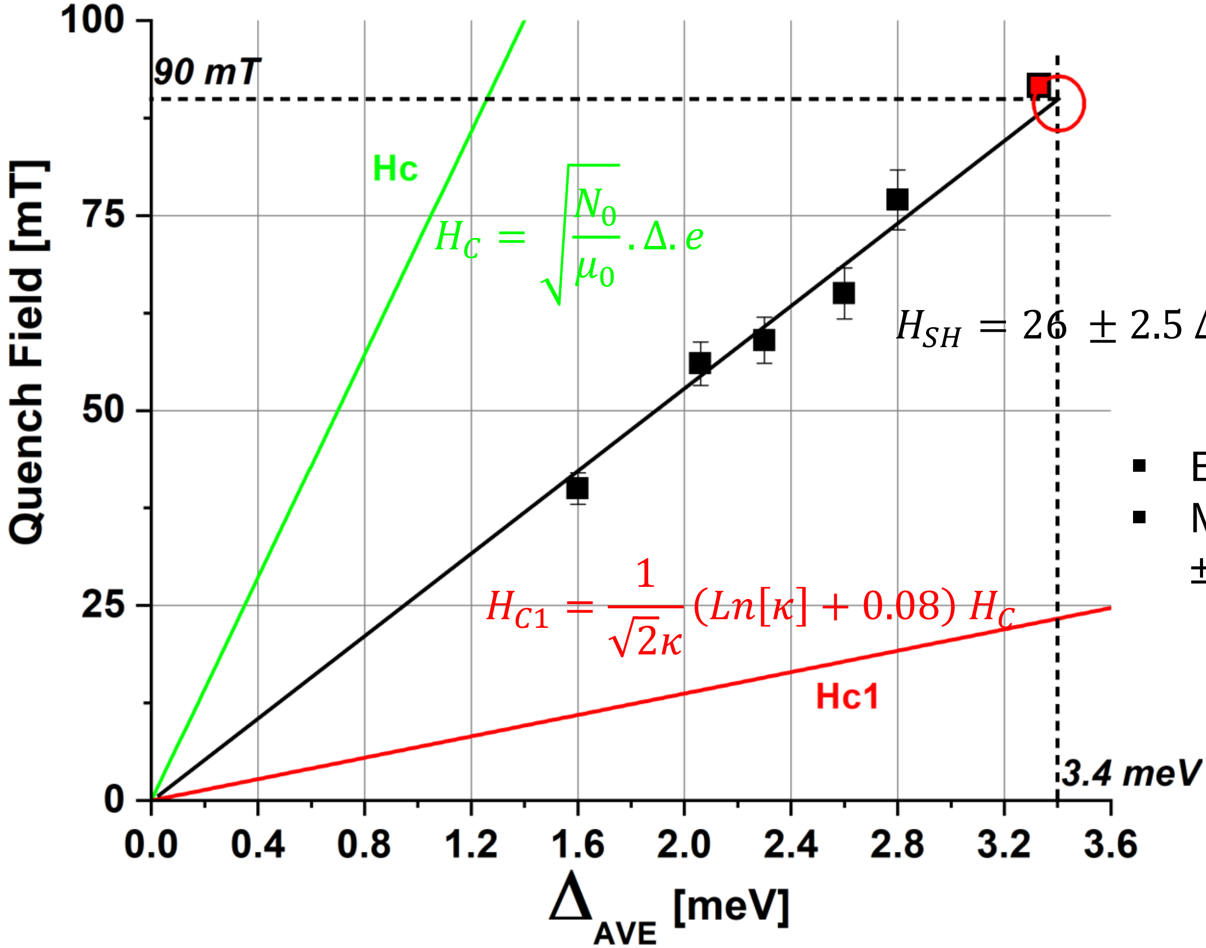



- phase riche Nb ~ 17.5 - 23%
- Interface Nb-$Nb_3Sn$ , grain boundaries
- Pockets near the surface

- Crystallites ~ 100 - 200 nm (XRD)

# $Nb_3Sn$/Nb (Cornell - FNAL) – PCT

## Quench field vs Average Gap




For large κ (λ/ξ = 24)

- Bulk Δ for Nb3Sn is 3.4 to 3.5 meV
- Max expected Quench field is ~ 91 ± 2 mT = 22 MV/m

- Linear dependence of Emax on the average surface gap (~300x300 µm)
- $H_{SH}$~3.5 times the $H_{C1}$ but why this gap dependence? Roughness, effective penetration depth?
- A15 compounds ($V_3Si$, $Nb_3Sn$, $Nb_3Al$…) are good for $Q_0$ and higher operation temp. (4,2 K)
- But what about $E_{MAX}$ ? How to increase $E_{MAX}$ ?

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## ***Summary:***

- Enable testing surface treatments/heterostructures on coupons prior to cavity tests
- Faster turner over and phase space exploration of growth parameters etc…
- Measurement of $Nb_3Sn$ sample from FNAL
- Nb3Sn : linear dependence of Emax and the superconducting gap.
- Nb: à déterminer.

## ***Future:***

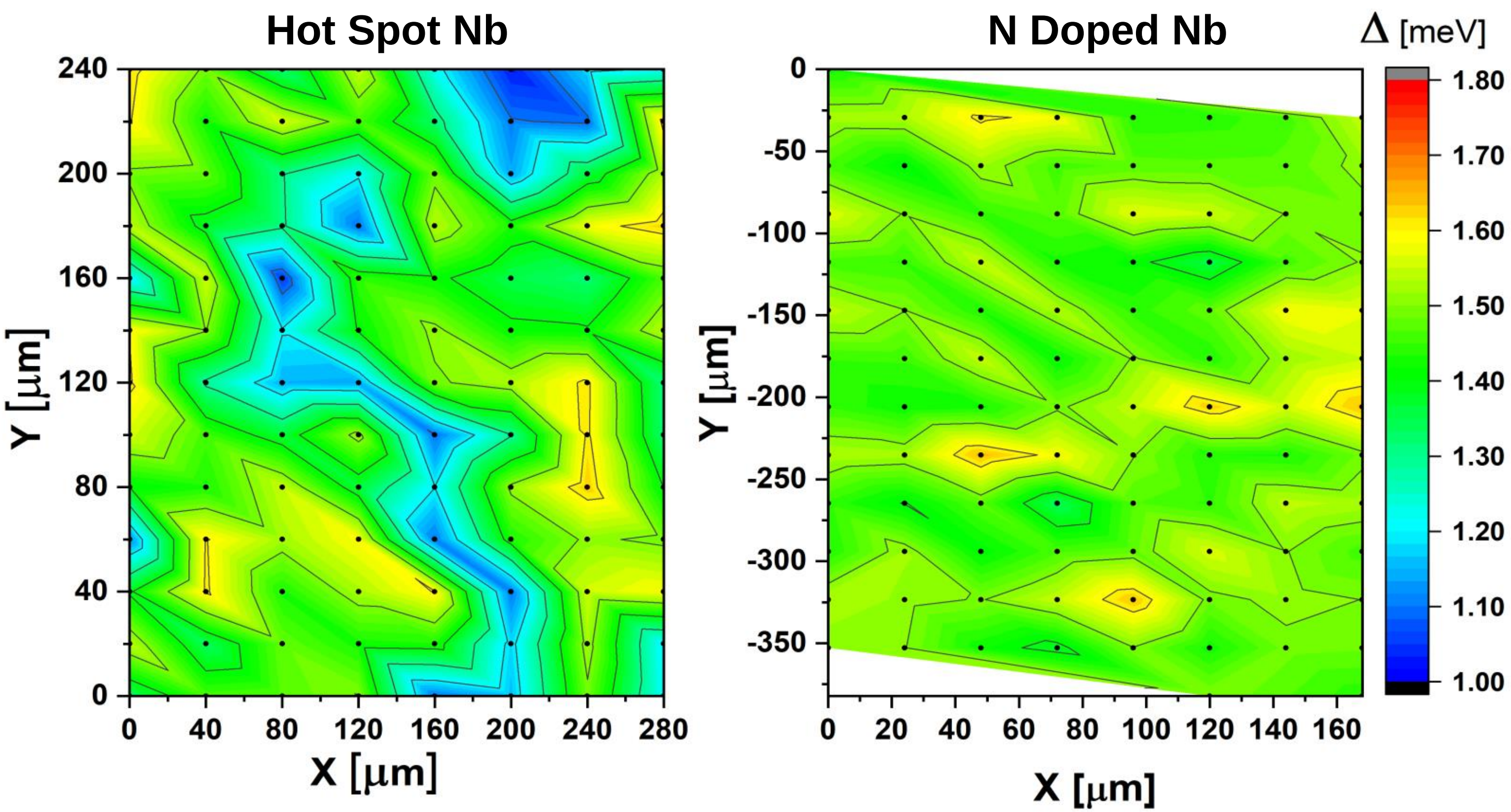
- Faraday Cage to improve noise (ordered) ~ 3 months.
- Measure of infusion in bulk Nb and Nb3Sn thin films from DESY, Jlab, STFC.
- Bulk Nb: Correlation between inhomogeneous properties and samples measurements
- Smaller scan areas < 1 µm.

Thanks you

The END

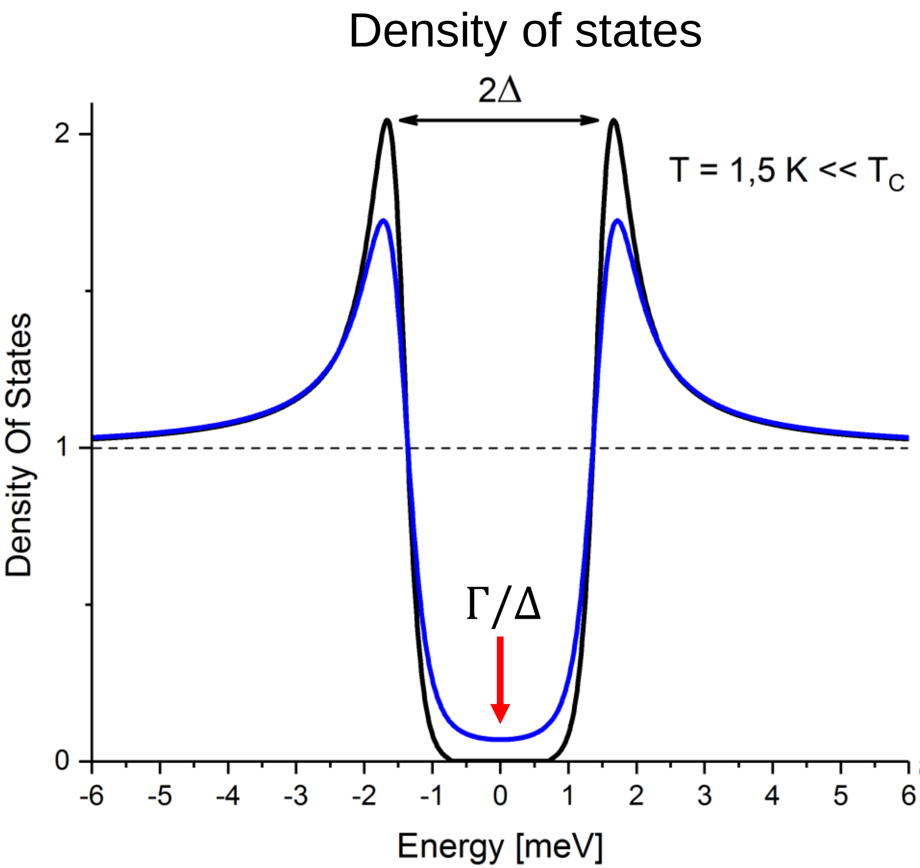
## Funding Sources

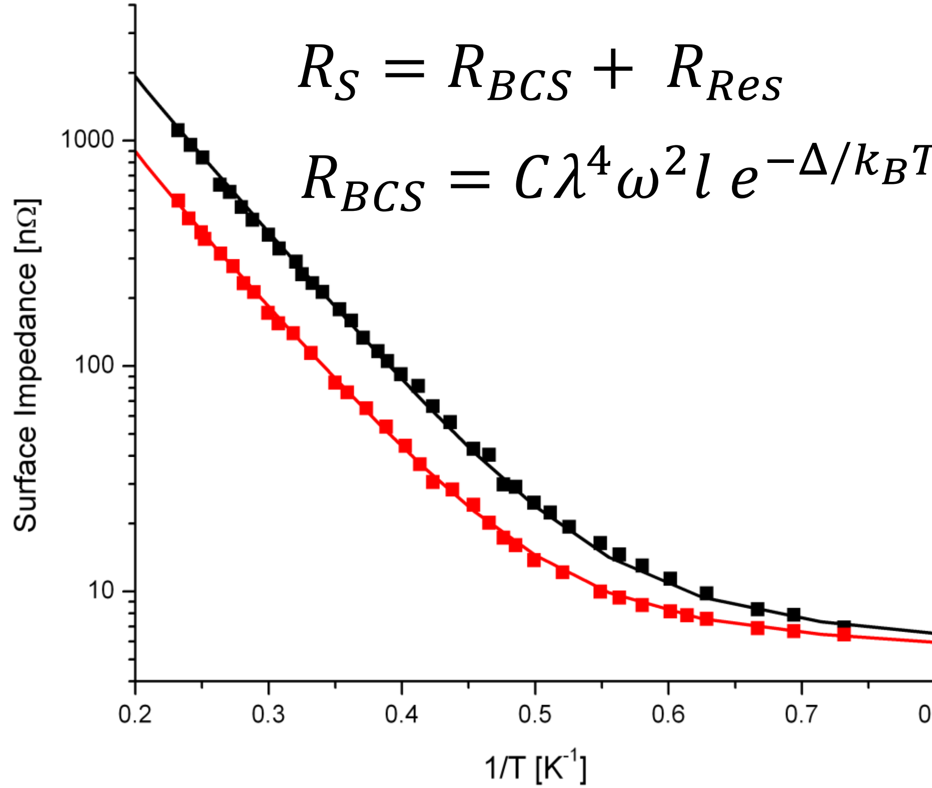
# Cartography




- N doping: Homogeneous bulk Nb gap values on the surface
- Hot spot: Regions with low superconducting gap values that can be fitted with normal metal regions on the surface (presumably hydrides)

# Tunneling spectroscopy: what do we measure and why?



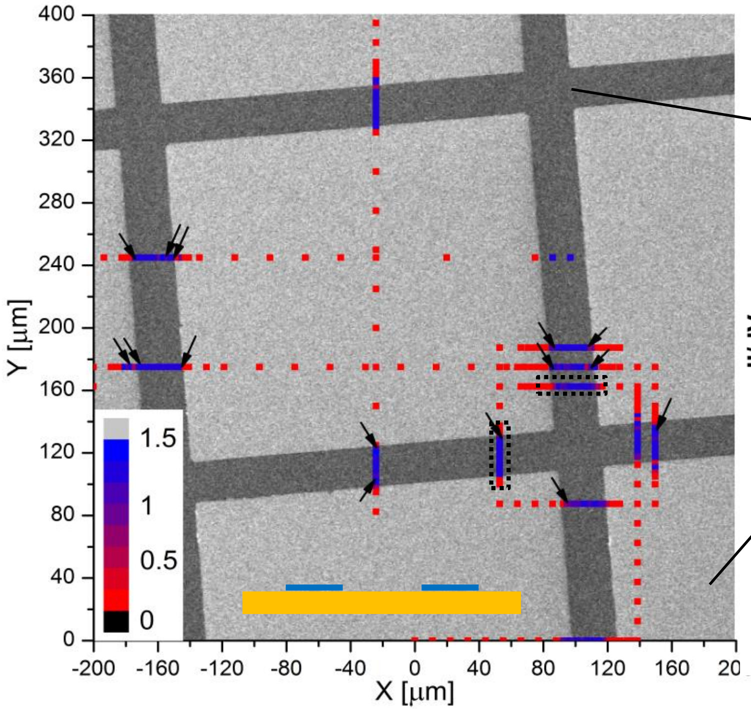



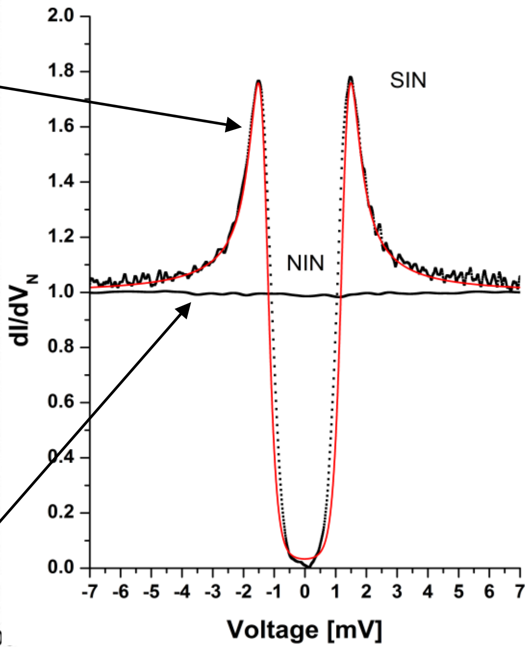

$$R_S = R_{BCS} + R_{Res}$$

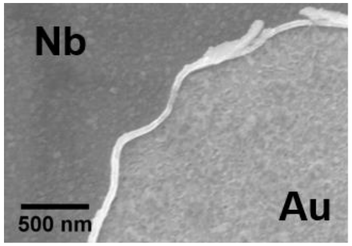
$$R_{BCS} = C\lambda^4\omega^2 l\, e^{-\Delta/k_B T}$$

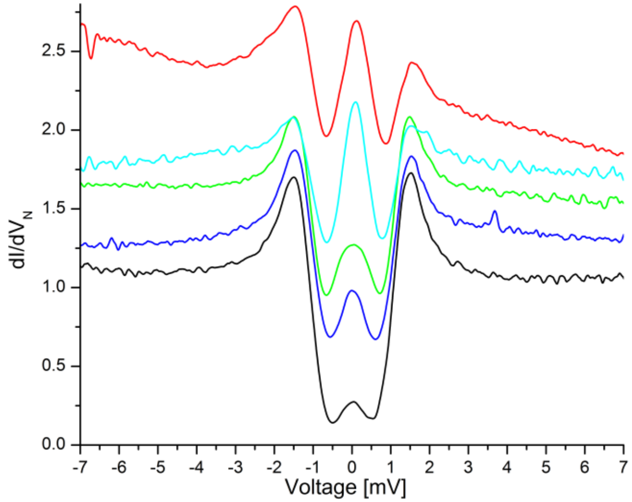
- Rs depends on DOS($E_F$). DOS($E_F$) (B, T, Δ, r)
- Higher Gap (Δ) -> Higher Q
- DOS ($E_F$) ≠ 0 -> dissipation @ T=0 K
- DOS($E_F$) (B, T, Δ, r), $R_S$ = <DOS($E_F$) (B, T, Δ)>$_r$
- Saturation mechanisms of the DOS? -> Inelastic scattering (Γ)

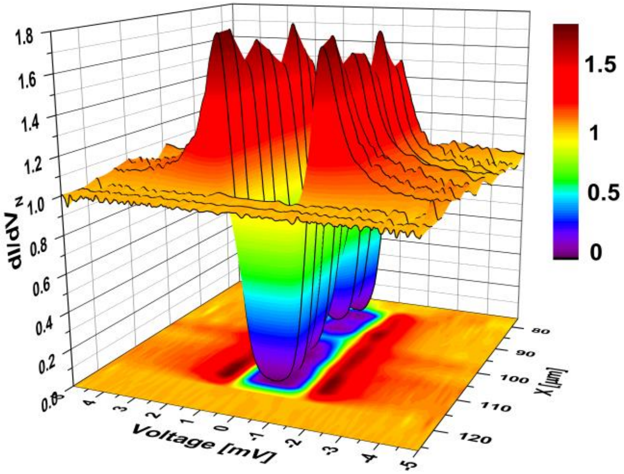
# Cartography: calibration



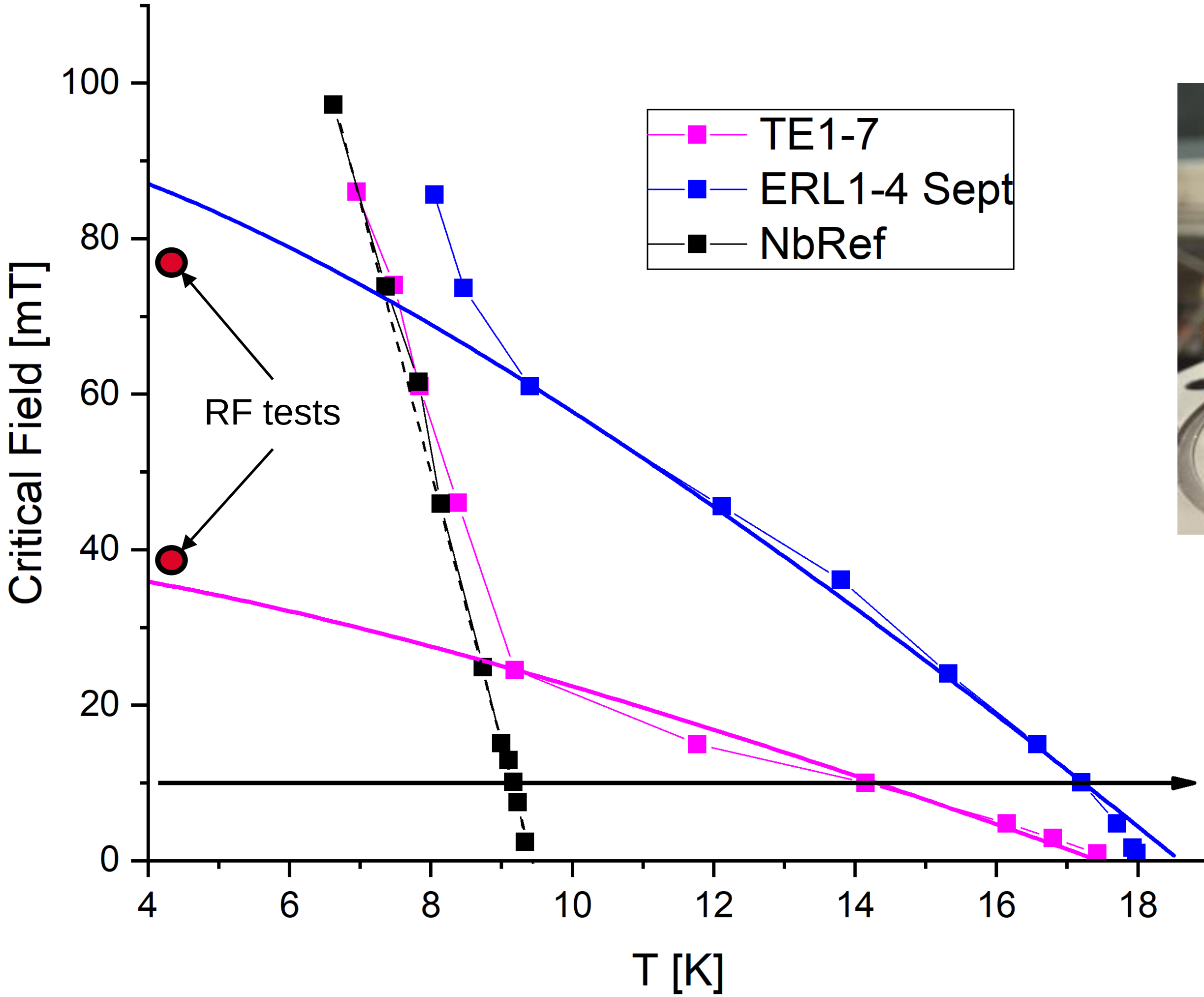



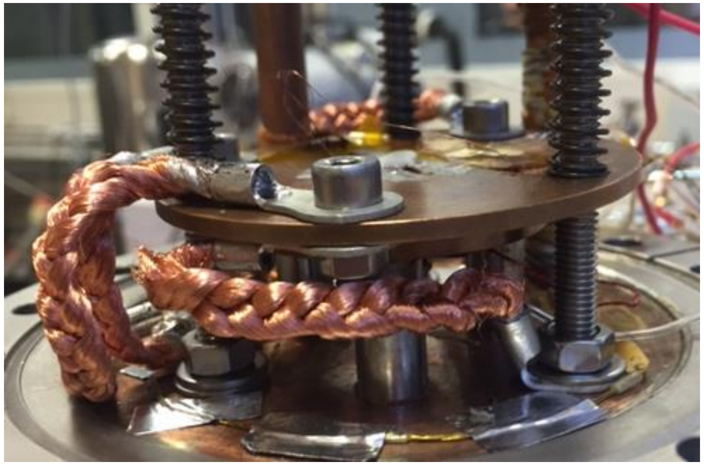




Standard:

- Lignes de Al(6 nm)/Nb (80 nm) sur Au (200 nm)
- Calibration: X = 4,1 nm/V
  Y = 4,9 nm/V
- Détails la DOS

# $Nb_3Sn$/Nb (Cornell) - Magnetometry

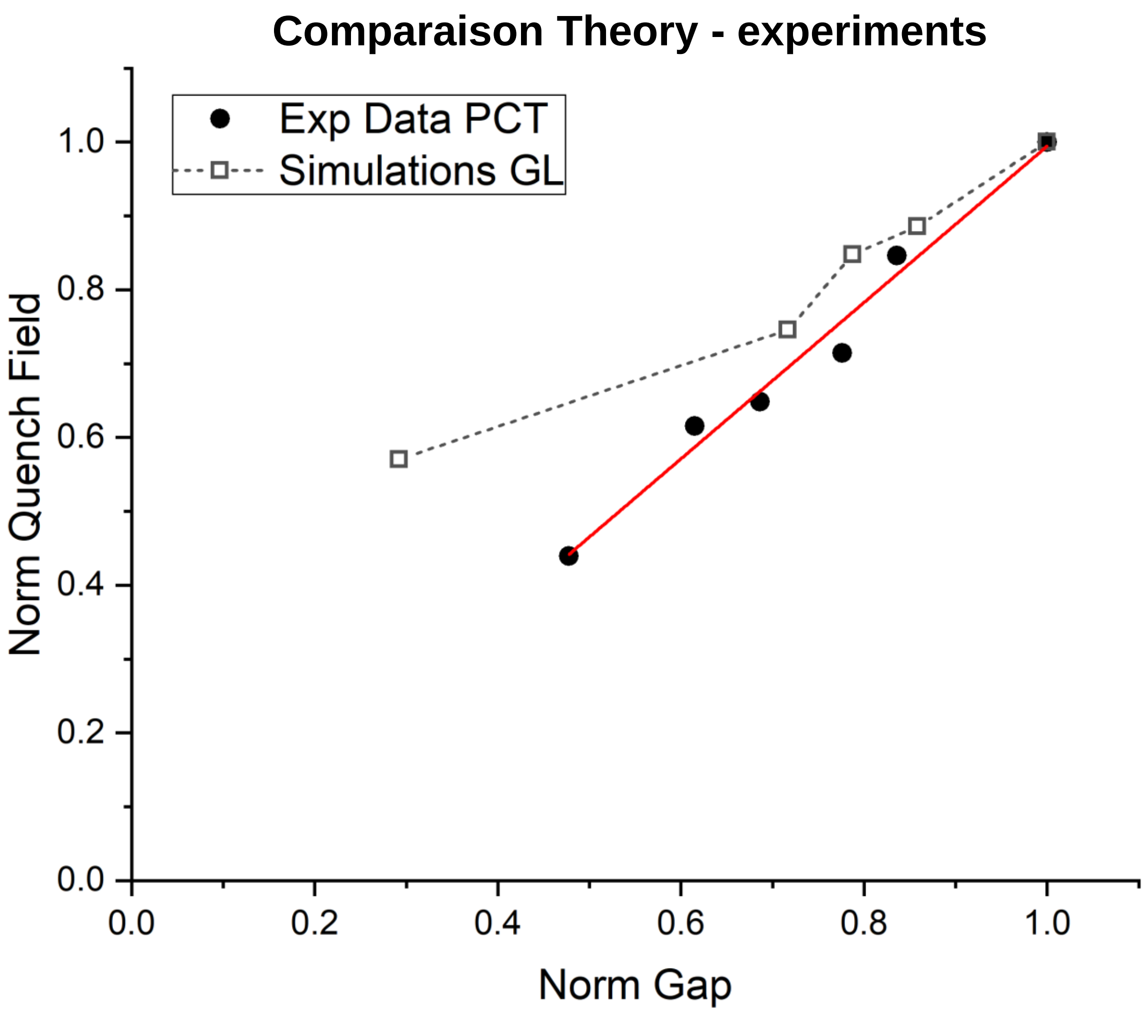


- Measure critical penetration field In Bulk and thin films samples
- Sample size: > 1 inch
- 4.2 K and 120 mT

- The critical field measured by Magnetometry correlates with RF tests Quench fields

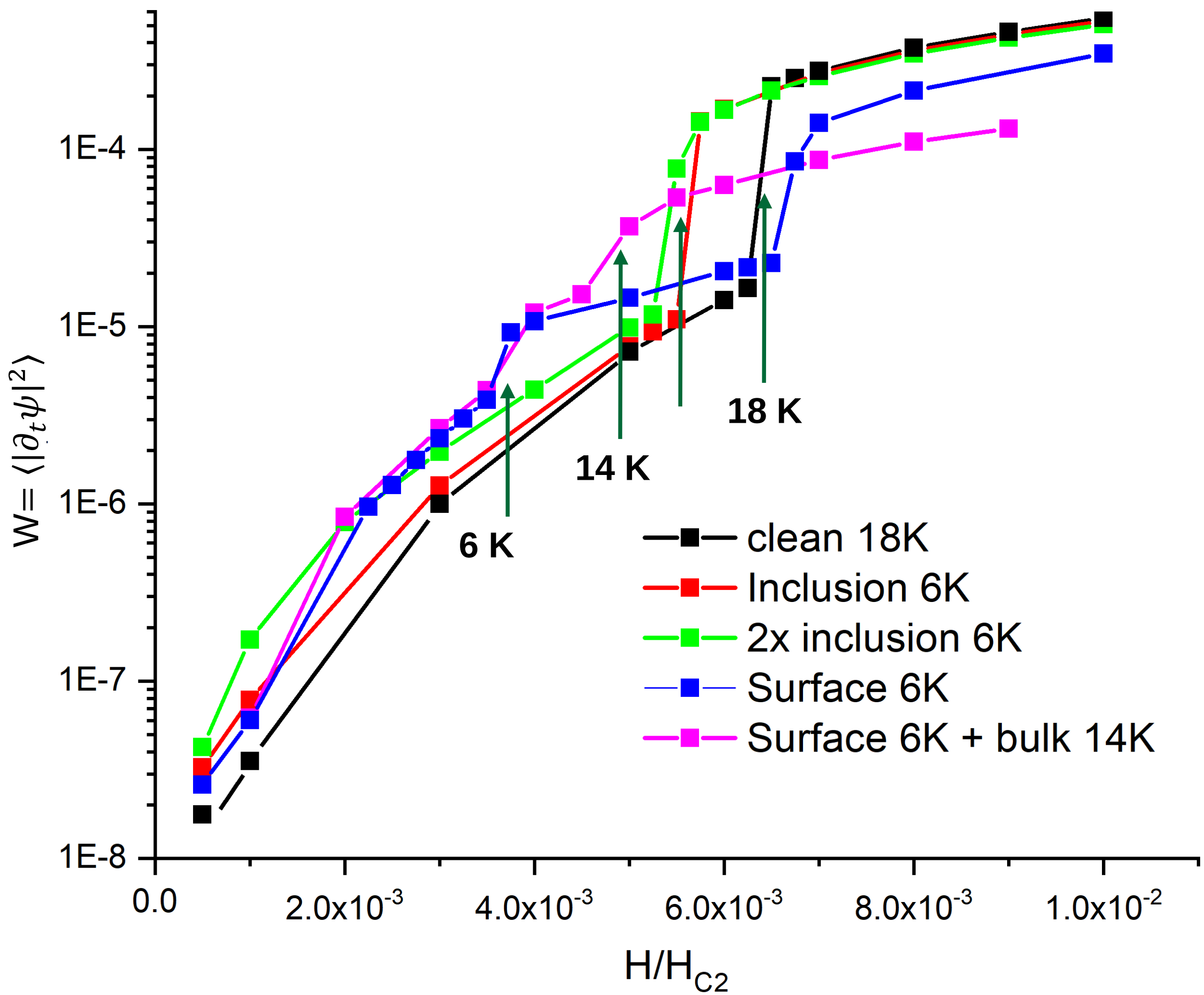
# $Nb_3Sn/Nb$




- Qualitative agreement between GL simul and PCT data
- To be continued

# $Nb_3Sn$/Nb - simulation

**Case of surface layer Low Tc 6K + lower bulk Tc 14K**




- Lower bulk Tc also lead to lower penetration field.