WG3 - Summary

Convenors:
Guillaume Rosaz
Teng Tan
Tobi Junginger

S1: Nb/Cu thin films

Development of coating system for the Wide Open Waveguide (WOW) Crab Cavity (10'+8') — *Fabio Avino*

Progresses on ECR plasma deposited Nb thin films (10'+8') — *Anne-Marie Valente-Feliciano*

Legnaro Thick films (10'+8') — *Cristian Pira*

500/1-001 - Main Auditorium, CERN 14:36 - 14:54

Test results of re-built LHC spare cavities (10'+8') — *M. Franck Peauger*

ARIES WP15 progresses (10'+8') — *Oliver Julius Kugeler*

500/1-001 - Main Auditorium, CERN 15:12 - 15:30

How to coat complex shapes?

Can thin films compete with bulk Nb?

How to mitigate Q-slope?

How does thin film structure impacts SRF performance?

Development of coating system for the Wide Open Waveguide (WOW) crab cavity

F. Avino *et al*

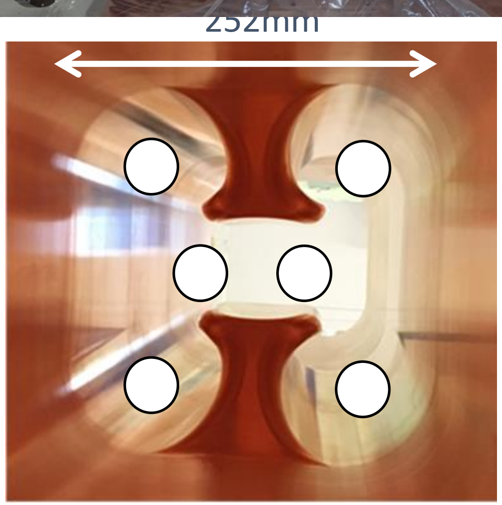
Motivation

More and more complex shapes to coat

Proposal

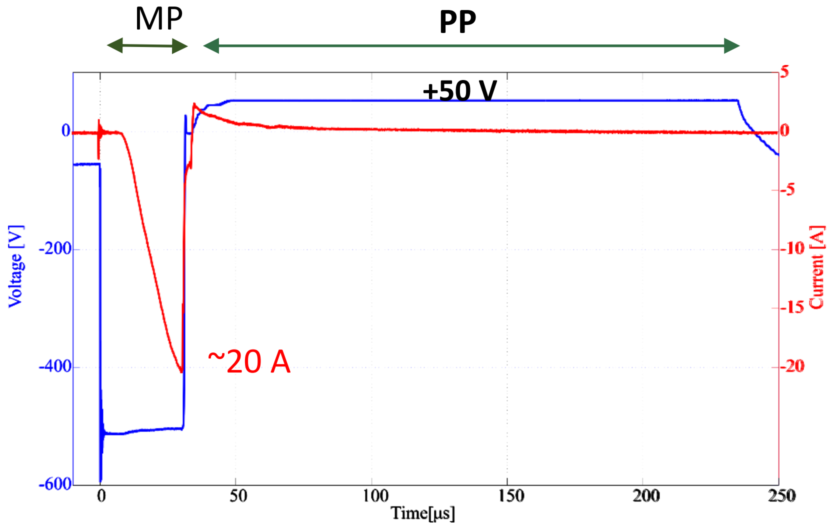
Use a HiPIMS discharge with voltage inversion to obtain a biasing effect

Outcome

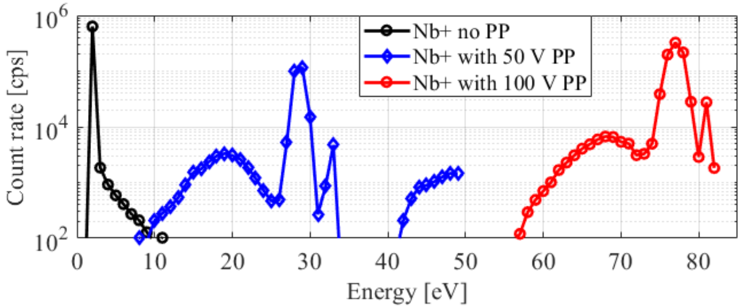


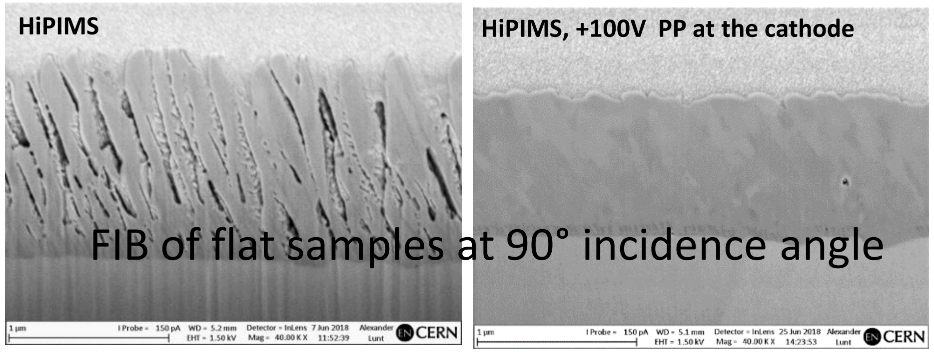
x6 Cylindrical magnetrons

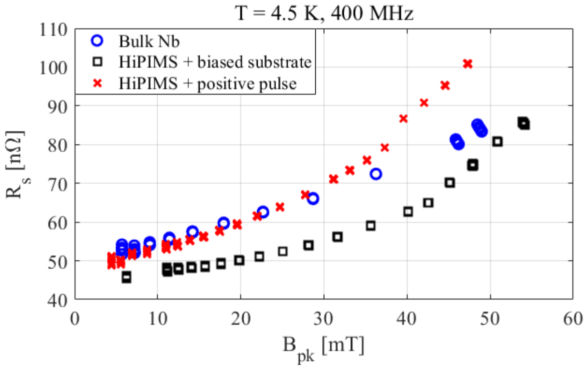
- Distances (20 – 80 mm)
- Angles of incidence (0 – 90°)



✓ **Densification at 90° incidence angle in HiPIMS + Positive Pulse (PP) at Cathode**







Progress with Nb/Cu film engineering with energetic condensation

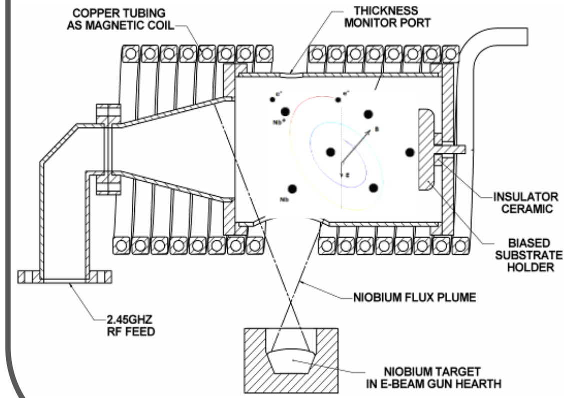
A.-M. Valente-Feliciano *et al*

Technique
Energetic condensation

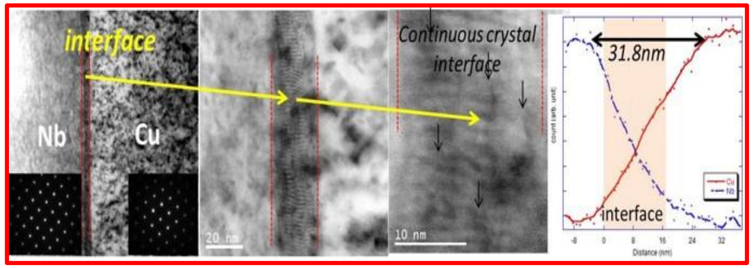
Possibilities
Interface engineering

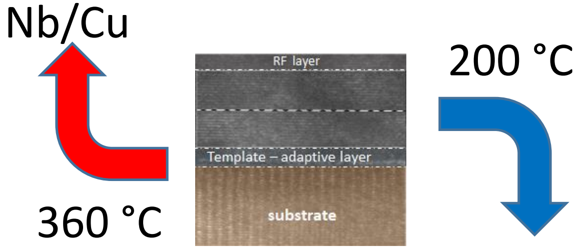
Conclusion
Fiber growth vs hetero-epitaxy

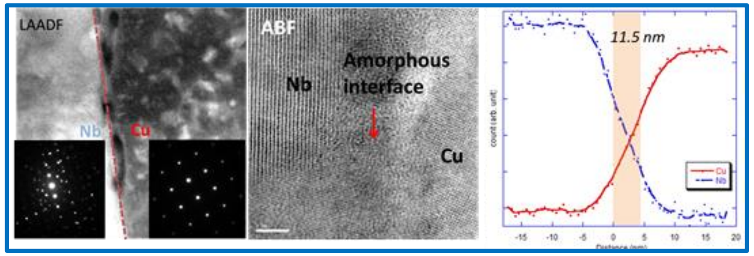
Electron Cyclotron Resonance (ECR)

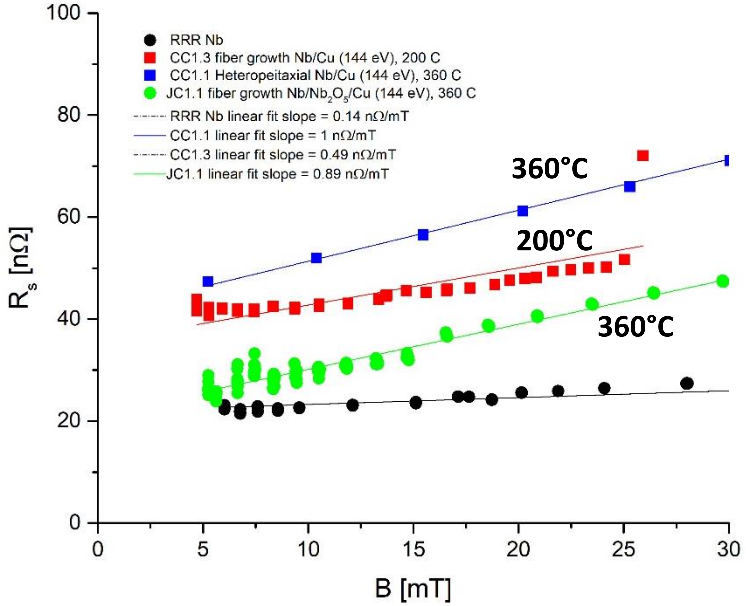


No working gas
Singly charged ions (64eV)
produced in vacuum
Controllable deposition energy
with Bias voltage
Excellent bonding
No macro particles









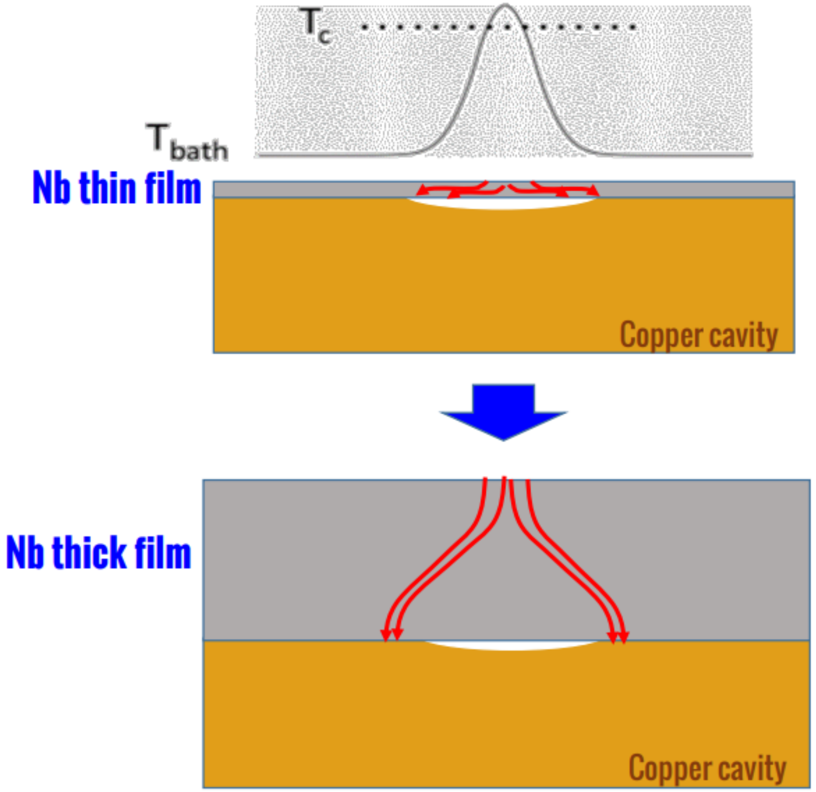
Fiber growth ECR Nb/Cu show better mitigation trend of the Q-slope

Legnaro Thick Films

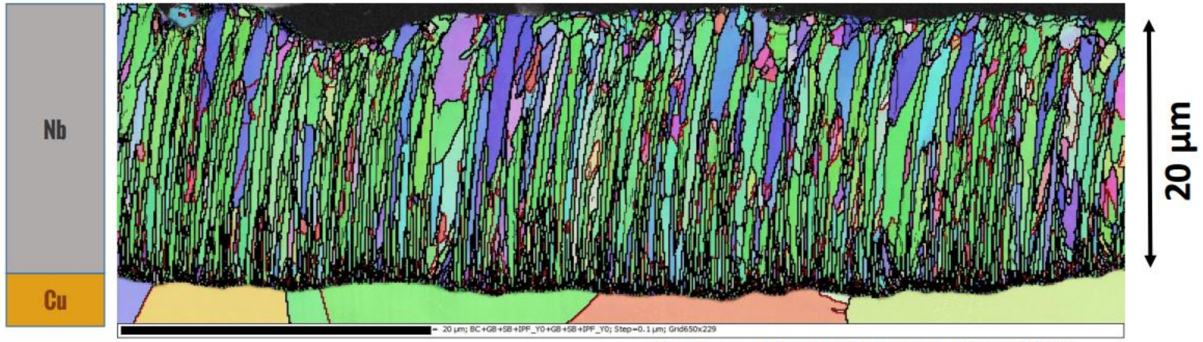
C. Pira *et al*

Method
Elaborate thick films by magnetron sputtering on 6GHz Cu cavities

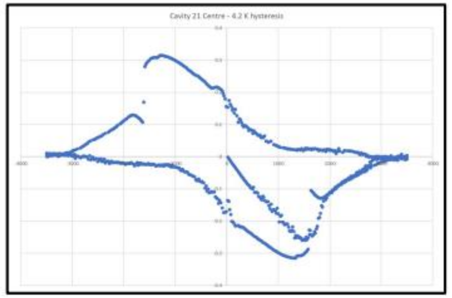
Motivation
Investigate by-pass effect of thermal defects



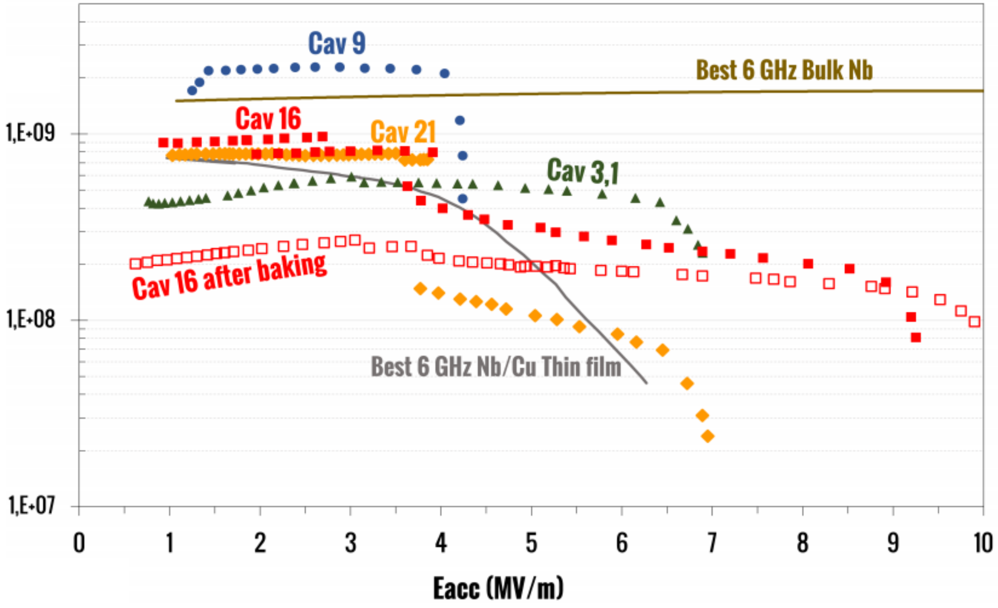
BULK LIKE PROPERTIES ON A FILM → Thick films increase grain dimensions and RRR



EBSD Micrograph of cavity #4, Courtesy of Reza Valizadeh (STFC)



- Grain dimension > 1 µm
- RRR > 60



Outlook

Q-slope mitigation obtained with Thick –films

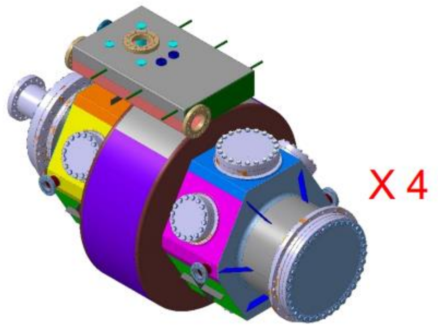
Reproducibility very likely due to substrate effects

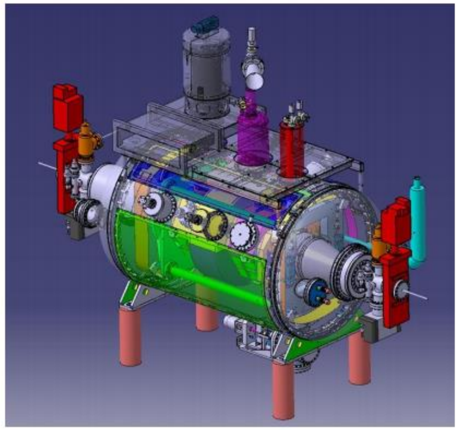
Test results of re-built LHC spare cavities

F. Peauger *et al*

Spare cavities program

- Only one spare dressed cavity and one spare cryomodule available
- New project started in 2015 to re-build and qualify four cavities and one quarter cryomodule*





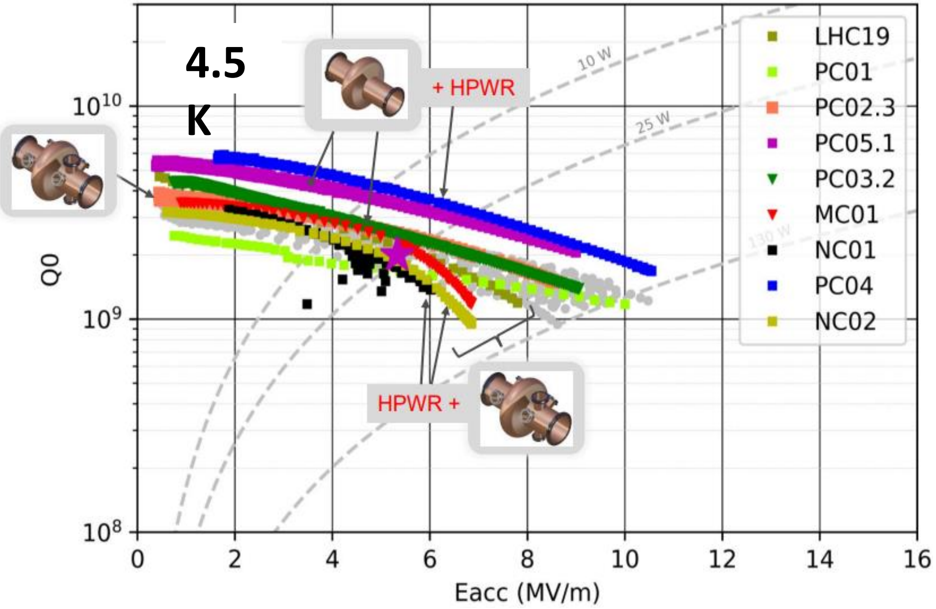
Simplified and “real” cavities

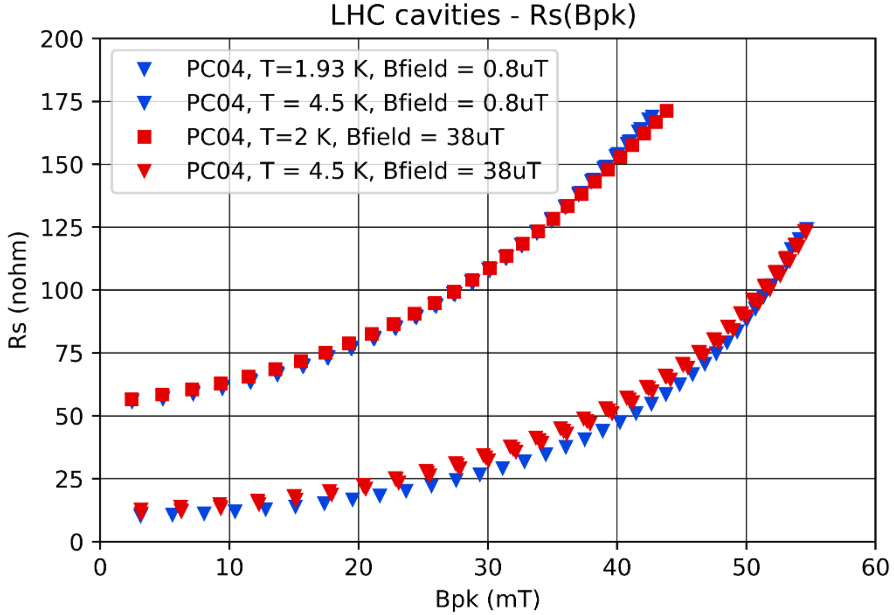
Simplified systematically perform better

Investigations on going to indentify the root-cause

Best simplified cavity tested in actively shielded cryostat

Very good performance
Rres = 12nOmhs
Very low sensitivity to trapped flux



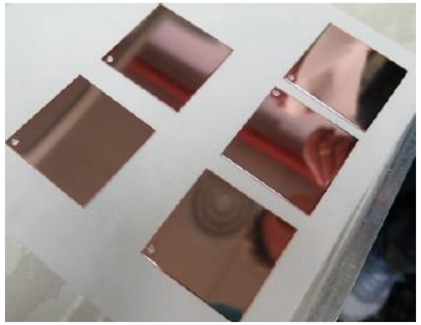


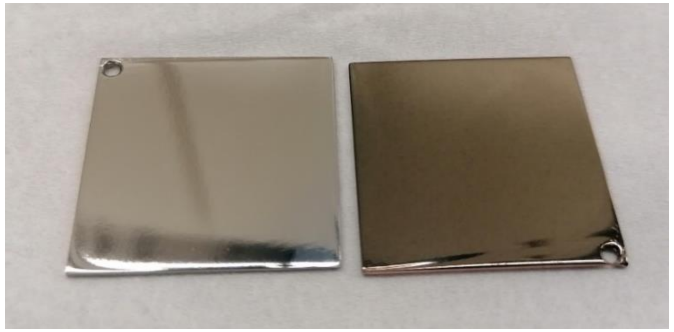
ARIES WP15 Thin Films progresses

O. Kugeler *et al*

From samples to QPR

Surface preparation optimization



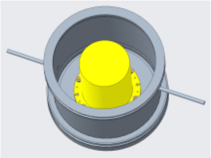


To QPR coating

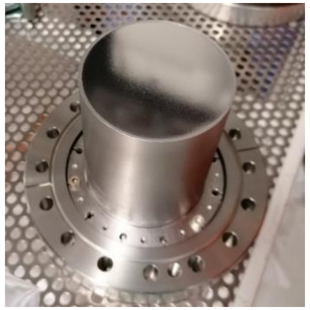
Surf. preparation, polishing (INFN LNL)

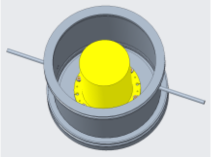
Niobium coating (Uni Siegen, CERN, STFC)

RF testing (HZB)



Shipping in transport box



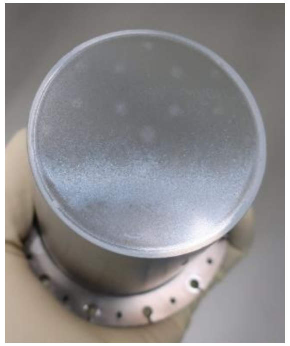


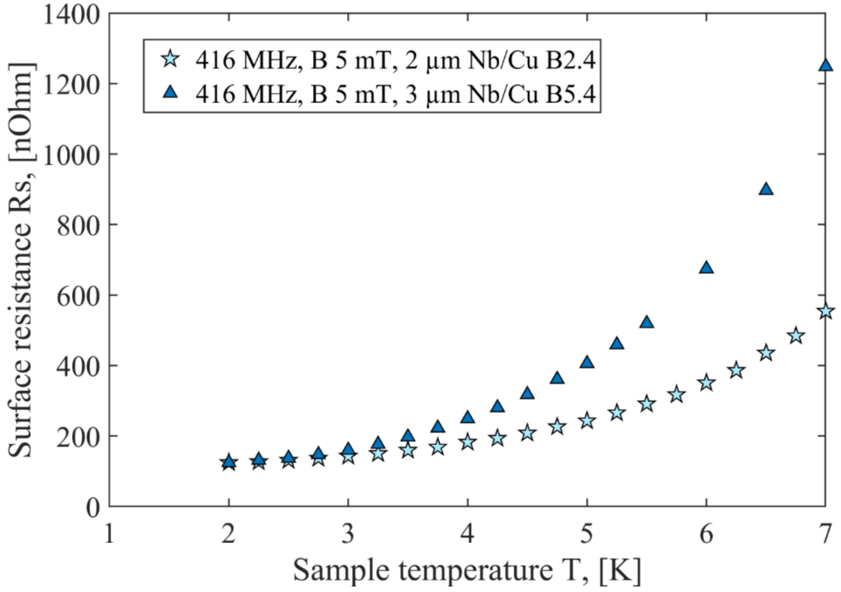
Shipping in transport box

First RF tests

B-2.4

B-5.4





Rres about 125 nOhms

Optimization on-going

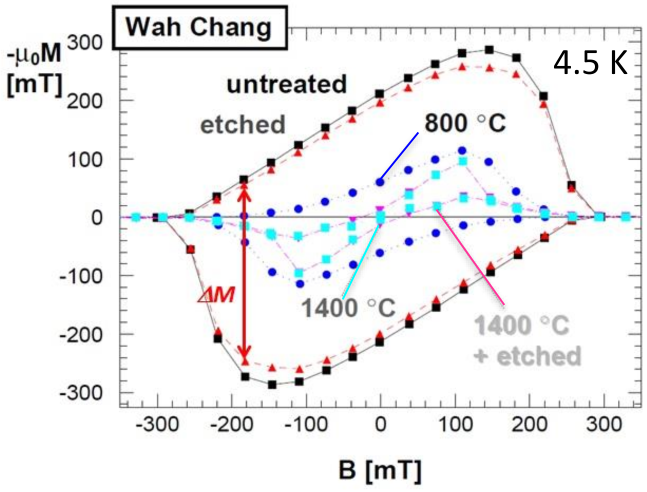
S2: Alternative structure/materials

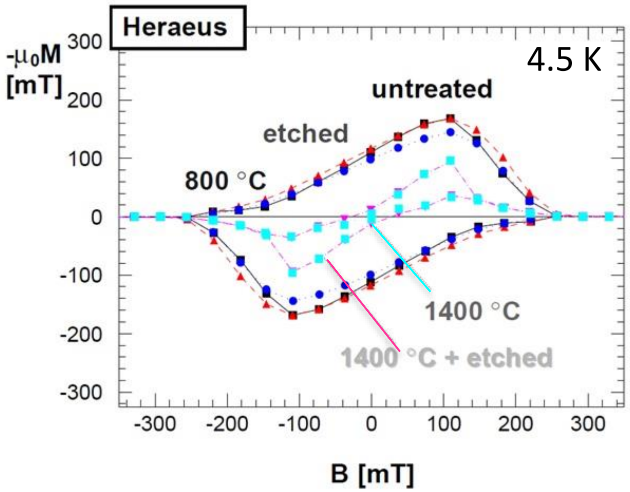
Recent SIS layer results (10'+8')	*Claire Antoine*	*500/1-001 - Main Auditorium, CERN*	16:00 - 16:18
Overview Multilayers RF results (10'+8')	*Sebastian Keckert*		
Nb3Sn/V3Si results (10'+8')	*Stephanie Fernandez*	*500/1-001 - Main Auditorium, CERN*	16:36 - 16:54
Two-stage coating of MgB2 system (10'+8')	*Hiroshi Sakai*	*500/1-001 - Main Auditorium, CERN*	16:54 - 17:12
CVD Thick Nb film and cavity coating (10'+8')	*Zeming Sun*	*500/1-001 - Main Auditorium, CERN*	17:12 - 17:30

- SIS structures
- Sputtering A15 thin film
- MgB_2 come back to life in LANL and KEK.
- CVD thick Nb films: new surface morphology.

Bulk Niobium vs thin films

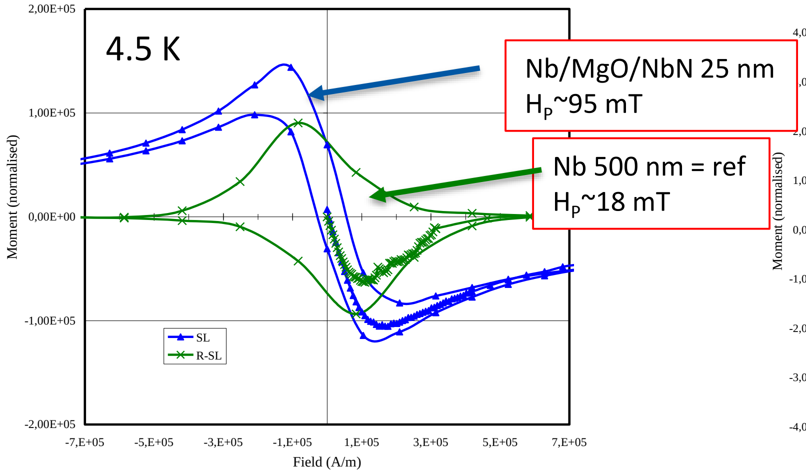
- Bulk : irreversibility (no vortex pinning) only if well recrystallized

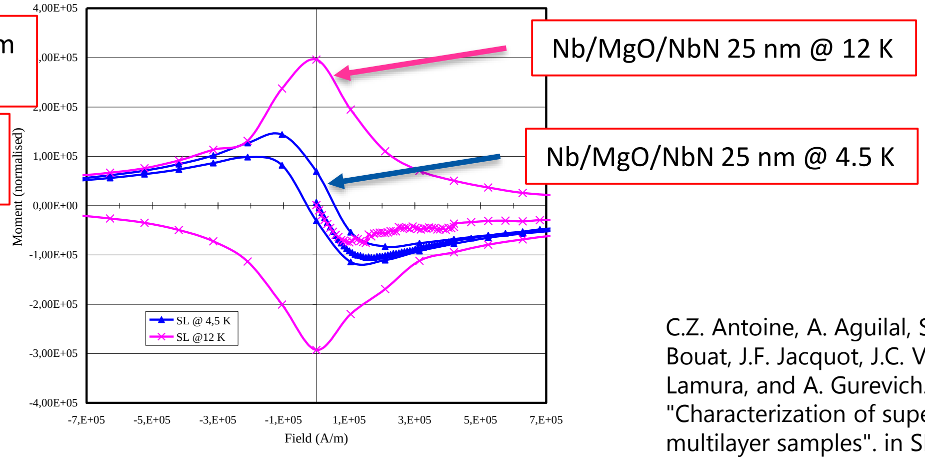




M. Bahte, F. Herrmann, and P. Schmuser, "Magnetization and Susceptibility Measurements on Niobium Samples for Cavity Production". Particle Accelerators, 1998. ***60****(1): p. 121-134.*

H // sample plane; longitudinal moment





C.Z. Antoine, A. Aguilal, S. Berry, S. Bouat, J.F. Jacquot, J.C. Villegier, G. Lamura, and A. Gurevich. "Characterization of superconducting multilayer samples". in SRF 2009. http://accelconf.web.cern.ch/accelconf/SRF2009/papers/tuppo070.pdf

- SIS : irreversibility => no vortex pinning <= no Vx entry ?

Each individual layer : ∃ defects, but combination = protected

S. Keckert RF measurement of SIS

- SRF characterization of multilayer structures with sample test cavities

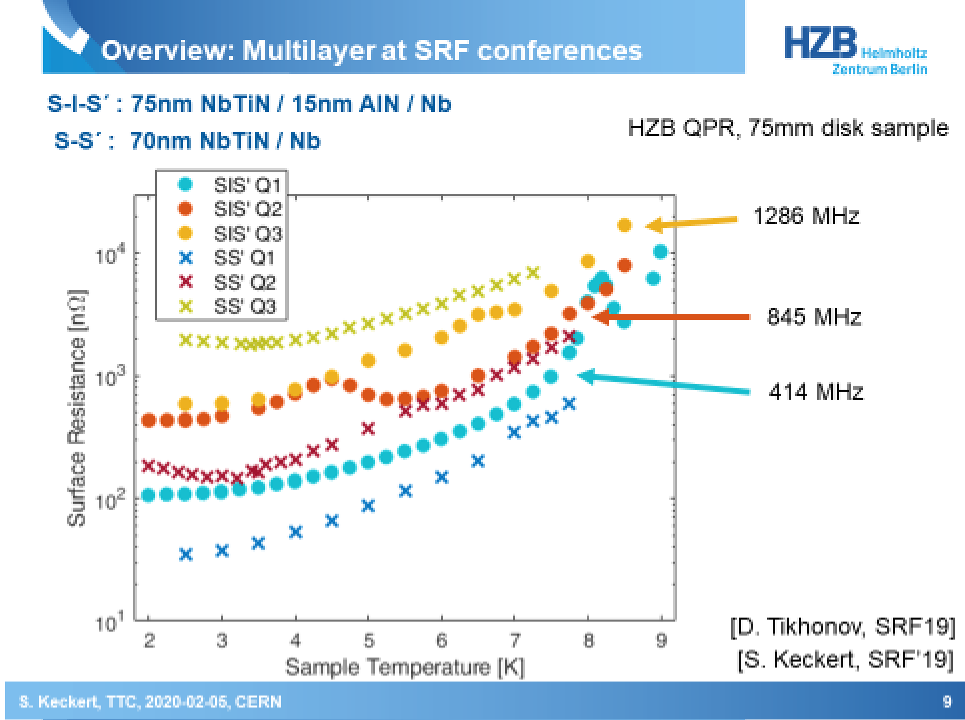
➔ So far: Mostly surface resistance data at high frequency and low field

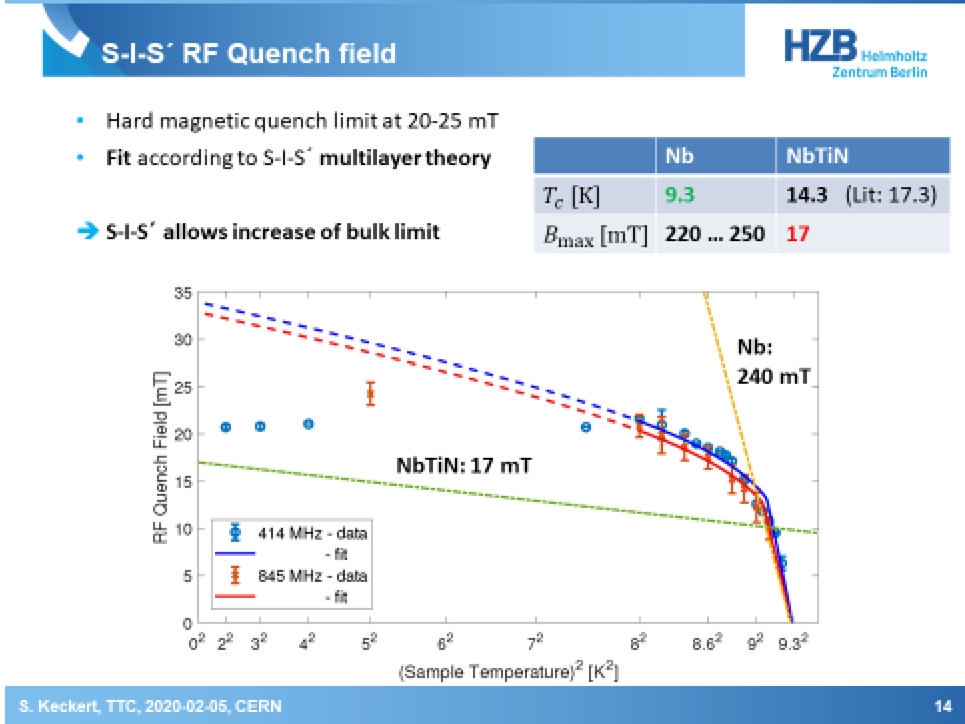
➔ Consistently: Lower R_S than for Nb at higher temperature
So far: Severe limitations by residual resistance

➔ Penetration depth measurement agrees with S-I-S´ multilayer theory

➔ First RF critical field measurements of S-I-S´ and S-S´ structures show low-field quenches

➔ We need more data on the RF quench field !



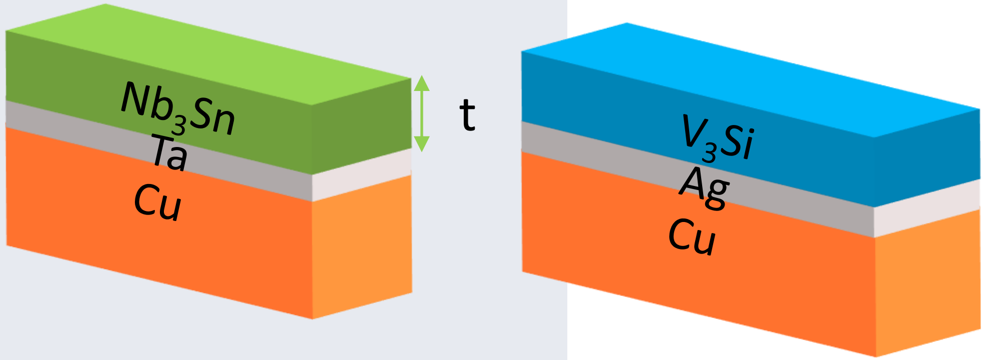


S. Fernandez Nb_3Sn and V_3Si from sputtering

Homogeneous composition across the surface of the QPRs

75 mm diameter

Film thickness may be the key



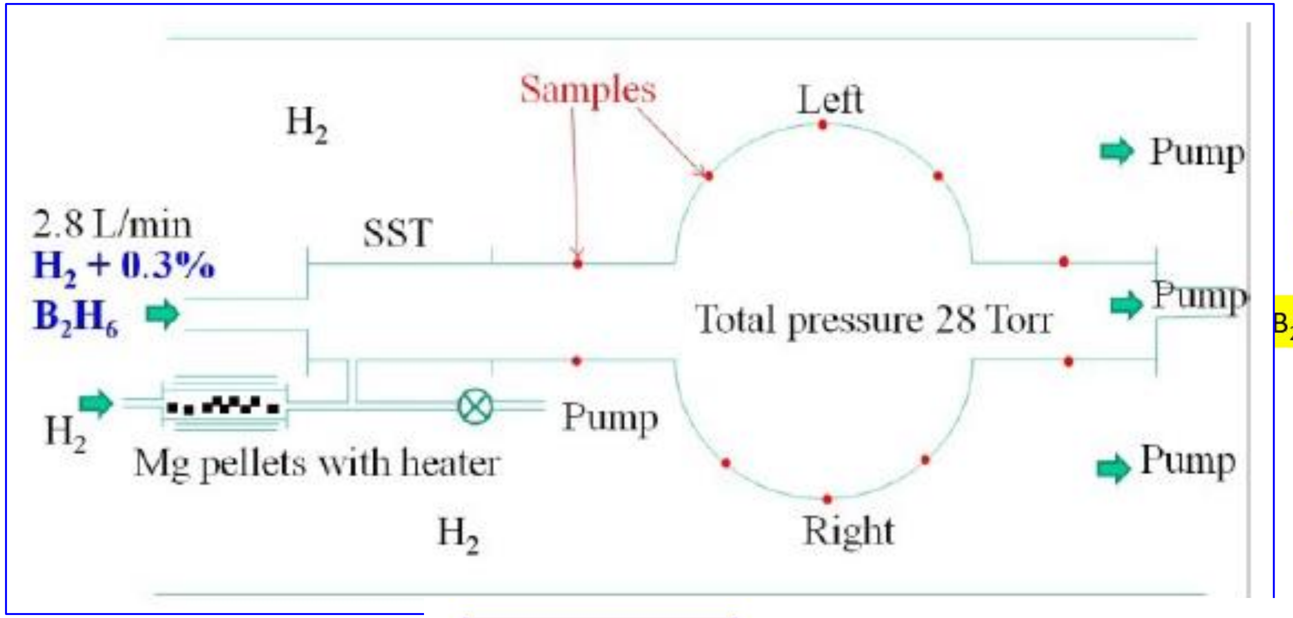
t vs London penetration depth

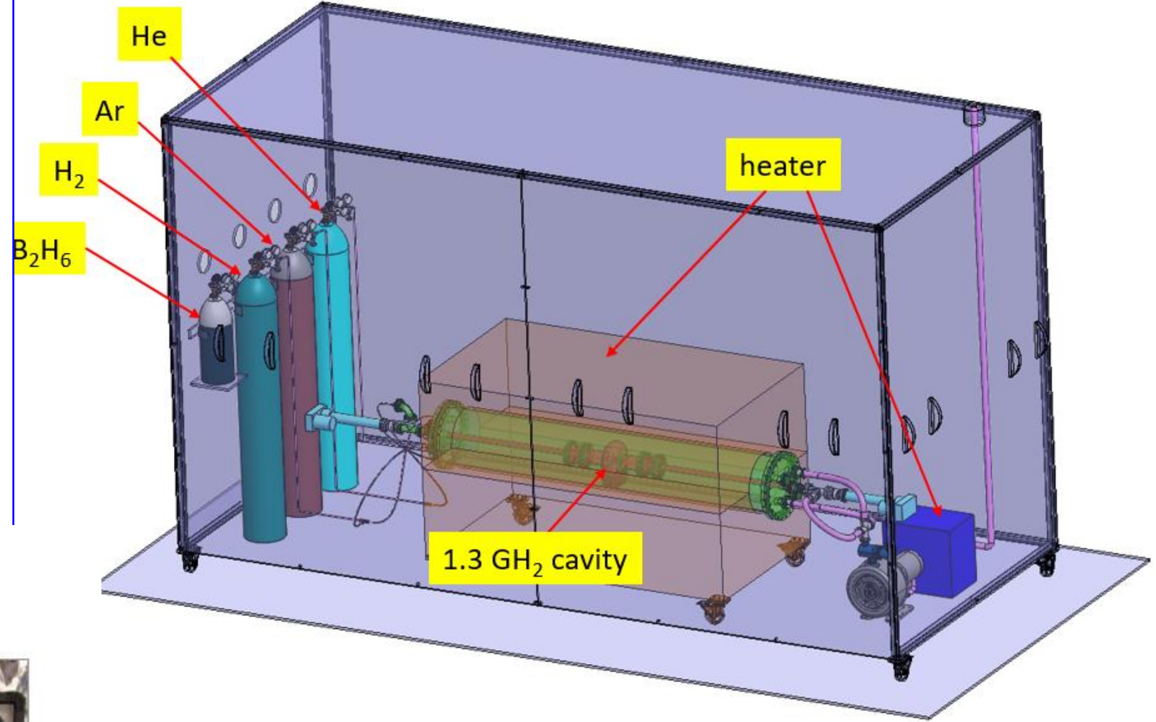
Atomic composition (%) measured in nine points along the disk

	Nb	Sn
1	77.9 %	22.1 %
2	78.3 %	21.7 %
3	78.5 %	21.5 %
4	77.9 %	22.1 %
5	78.2 %	21.8 %
6	78.8 %	21.2 %
7	78.1 %	21.9 %
8	78.3 %	21.7 %
9	78.7 %	21.3 %

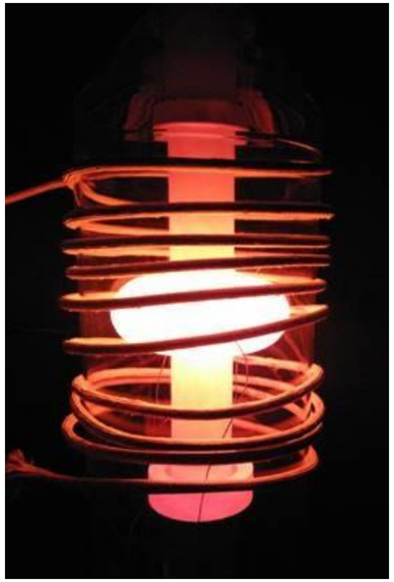
Sample	Recipe	Critical temperature (T_c)	Surface resistance (R_s)
QPR1	Nb_3Sn/Nb	14.5 K	1000 nΩ
QPR2	Nb_3Sn/Ta	11.5 K	25 nΩ
QPR3	Nb_3Sn/Ta	15 K	2000 nΩ
QPR4	Nb_3Sn (thick)/Ta	16 K	1000 nΩ

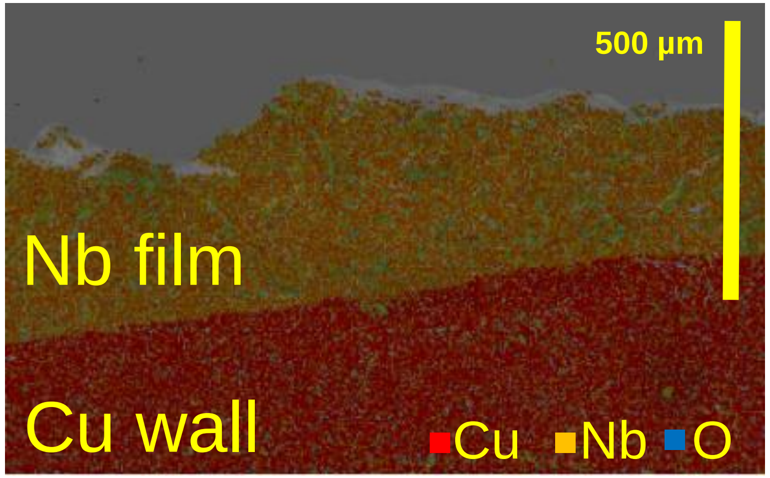
H. Sakai: MgB_2 revived at KEK and LANL

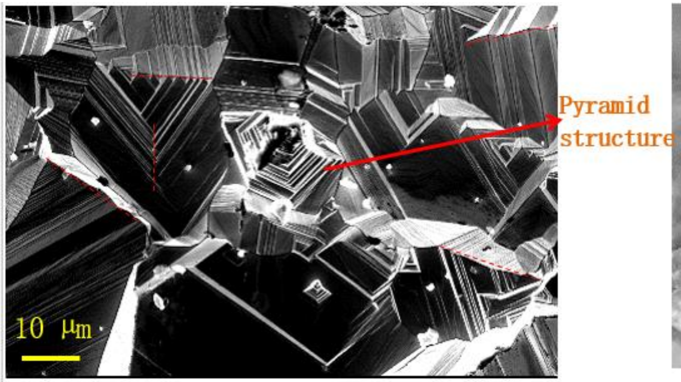




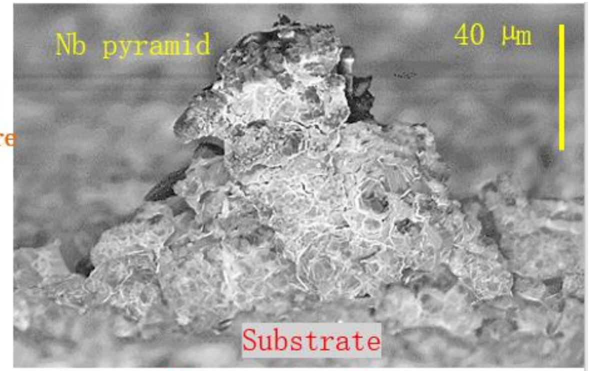
Z. Sun CVD thick Nb/Cu: from deposition to RF test



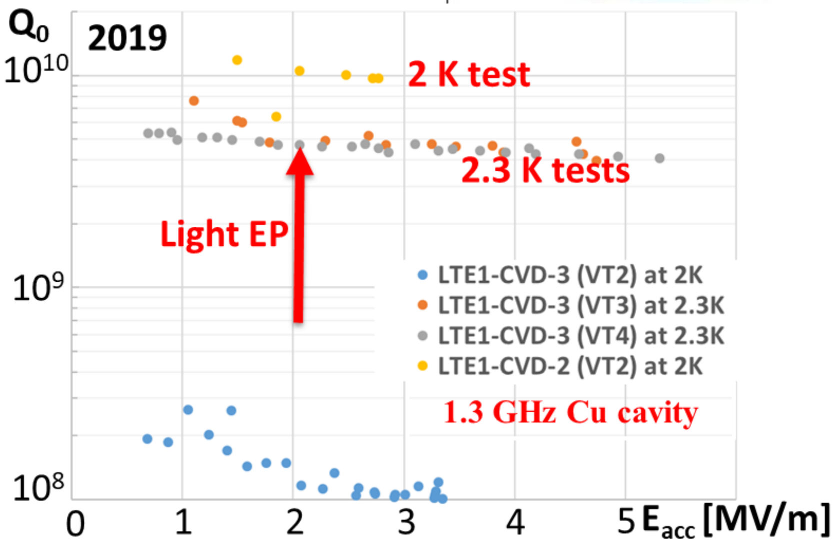




Surface imaging



Cross-section



EP was performed on thick Nb film

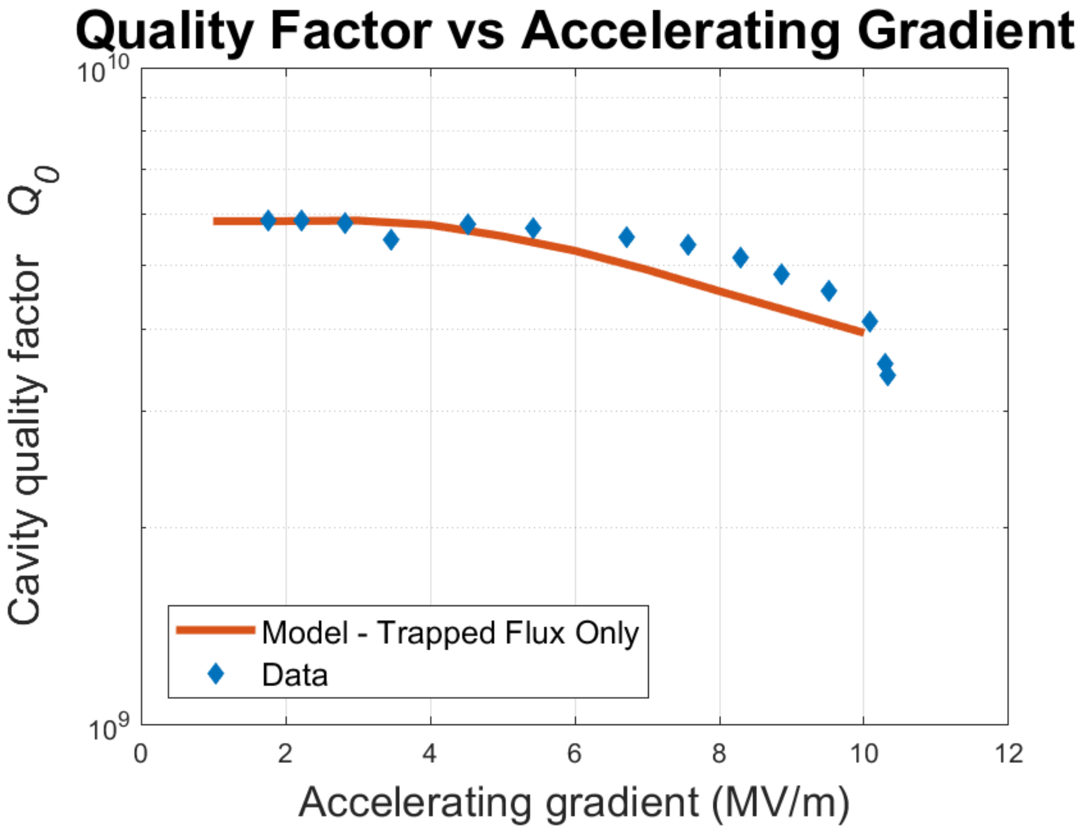
S3: Progress on Nb_3Sn towards accelerator

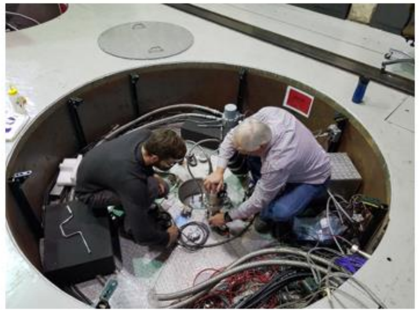
Nb3Sn progressess from Cornell (10'+8')	*Ryan Porter*
500/1-001 - Main Auditorium, CERN	09:00 - 09:18
Nb3Sn coated 1.5 GHz multi-cell cavities and perspectives for beam acceleration tests (10'+8')	*Grigory Eremeev*
Advances in Nb3Sn coating at Fermilab including recent world-record performance cavity results (10'+8')	*Mr Sam Posen*
Nb3Sn thin film synthesized via bronze route (10'+8')	*Akihiro Kikuchi*
Nb3Sn from the lab to the machine (10'+8')	*Rama Calaga*
500/1-001 - Main Auditorium, CERN	10:12 - 10:30

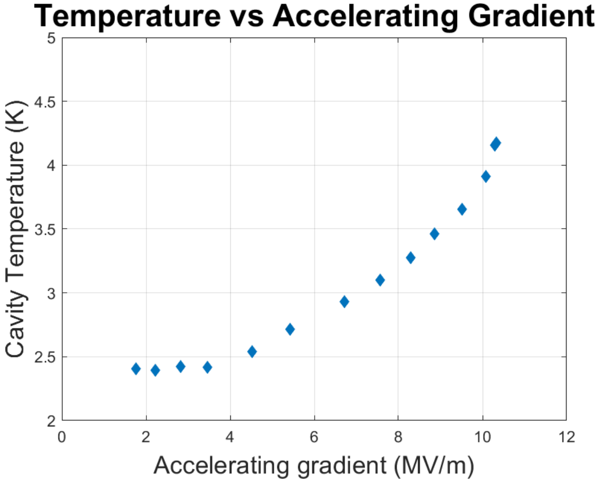
- Cryo-cooler driven, other deposition methods
- Multi-cell at Fermilab: two mode method for quench mechanism.
- New MP quench mechanism for Nb3Sn cavity. Hope for >24 MV/m
- Bronze route: another possibility
- Voices from outside TFSRF: what does the machine need

Cornell Laboratory for Accelerator-based Sciences and Education (CLASSE)

R. Porter: Nb_3Sn from Cornell



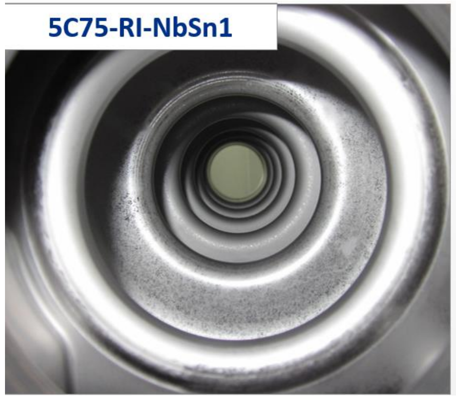


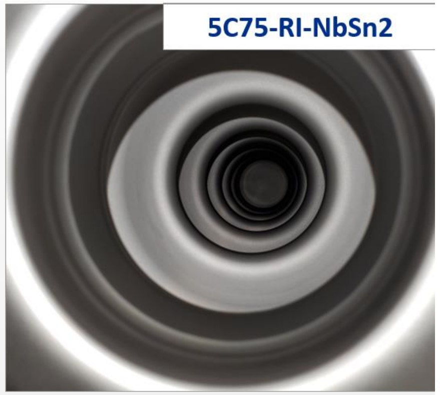


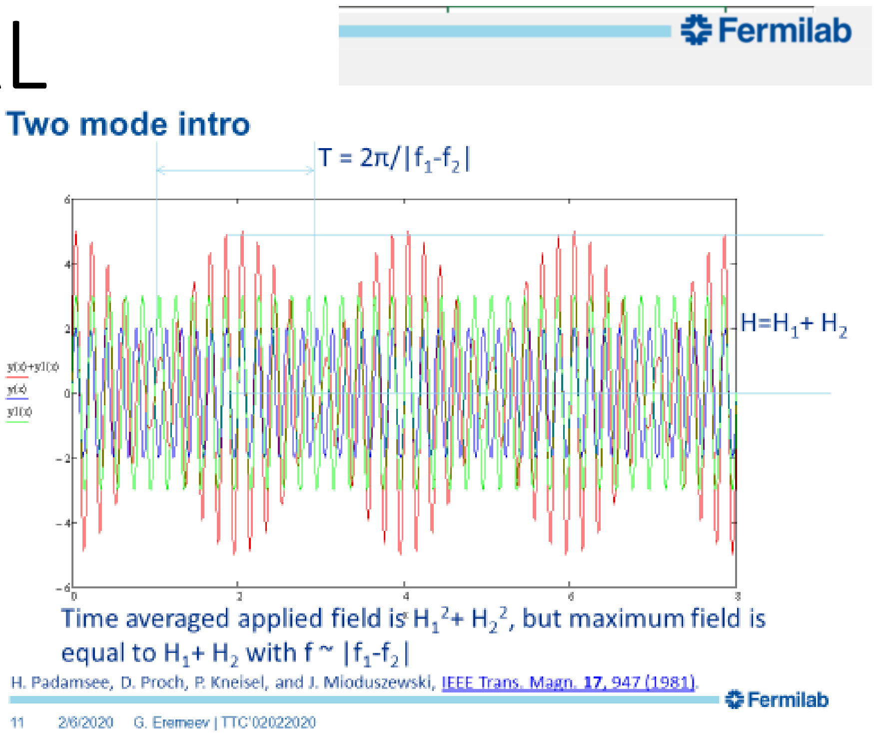
10 MV/m stable operation with cryo-cooler

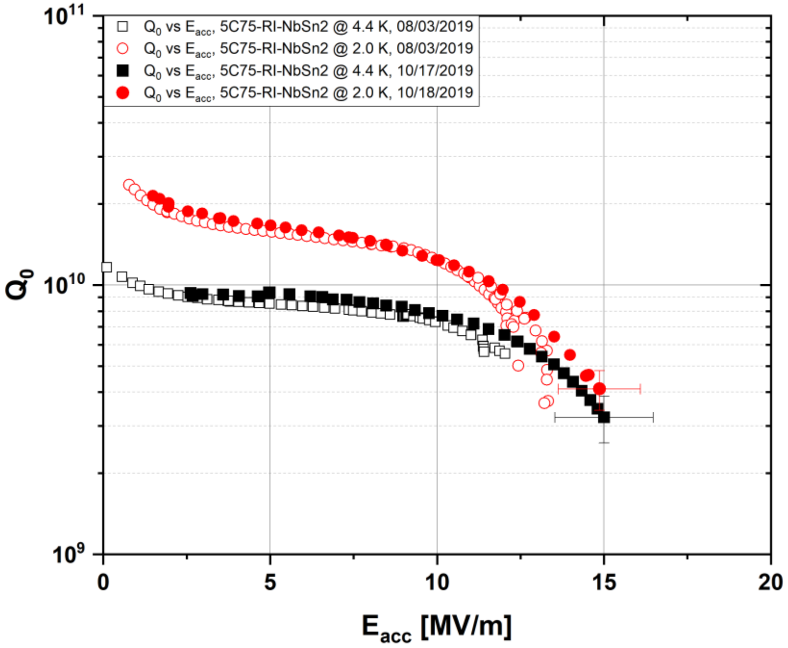
Some tries with other deposition techniques

G. Eremeev: Multi-cell Nb_3Sn from FNAL









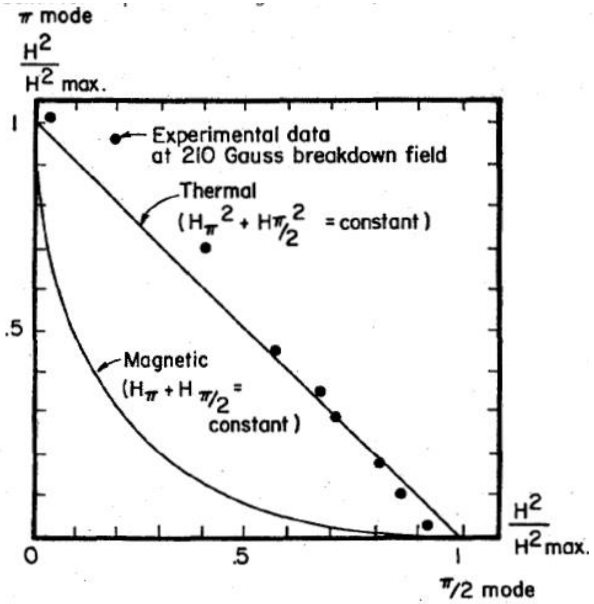
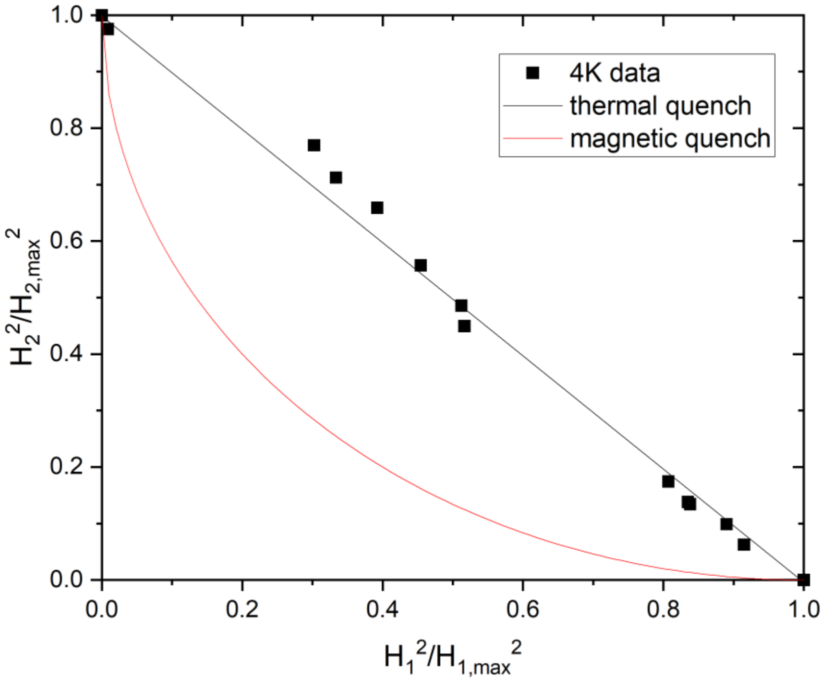
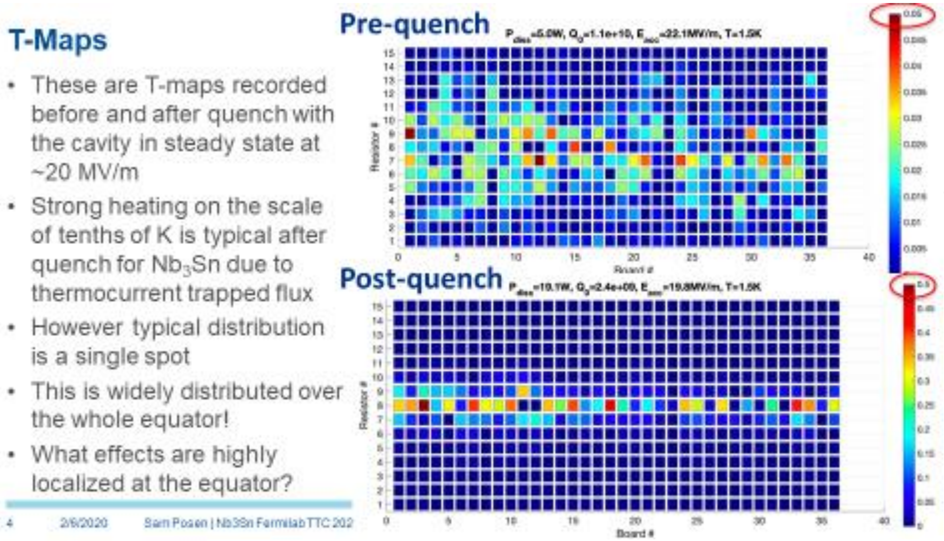


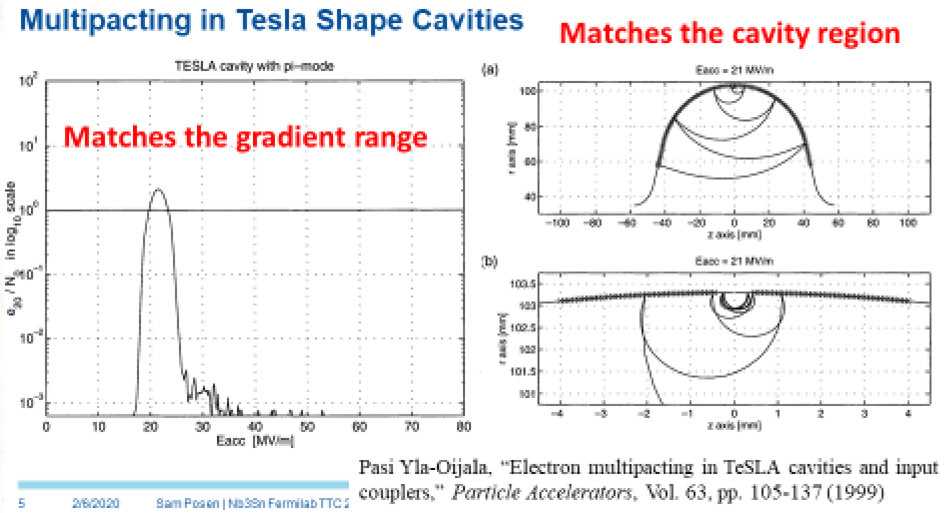
Fig. 4: Mode mixing experimental data to distinguish between thermal and magnetic breakdown.



“The data unambiguously supports the thermal model.”

S. Posen: New Quench Mechanism for Nb_3Sn

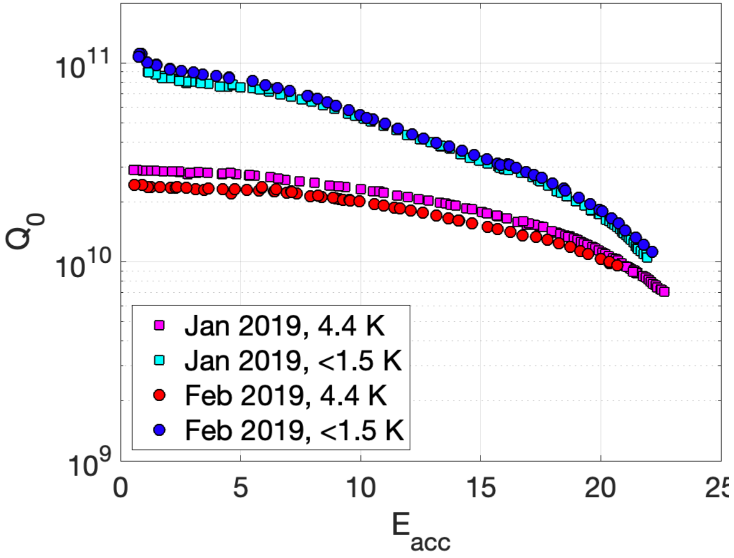


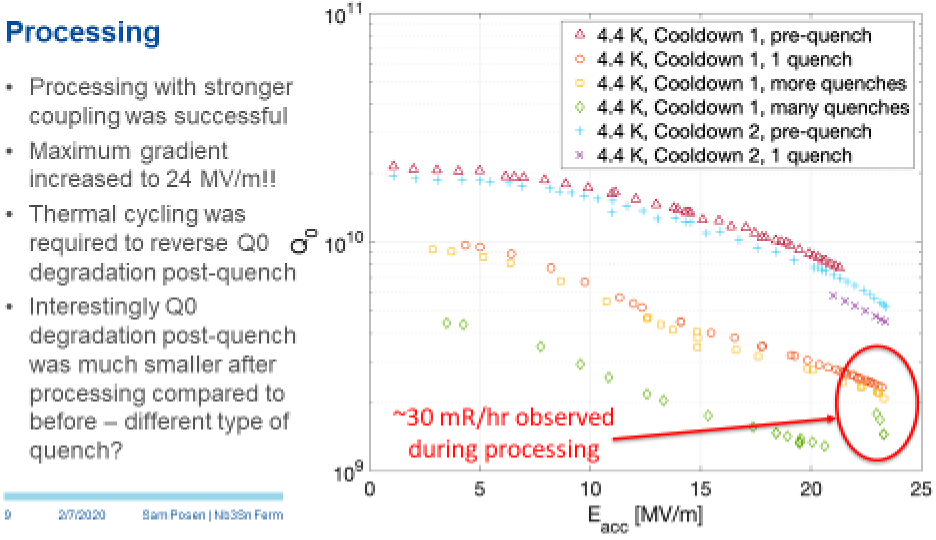


MP induced quench

Improved Q after processing

Going over 24 MV/m?

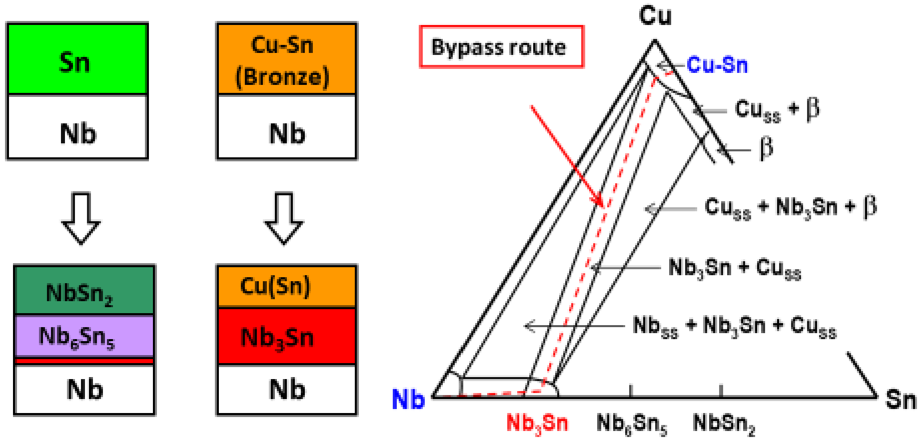


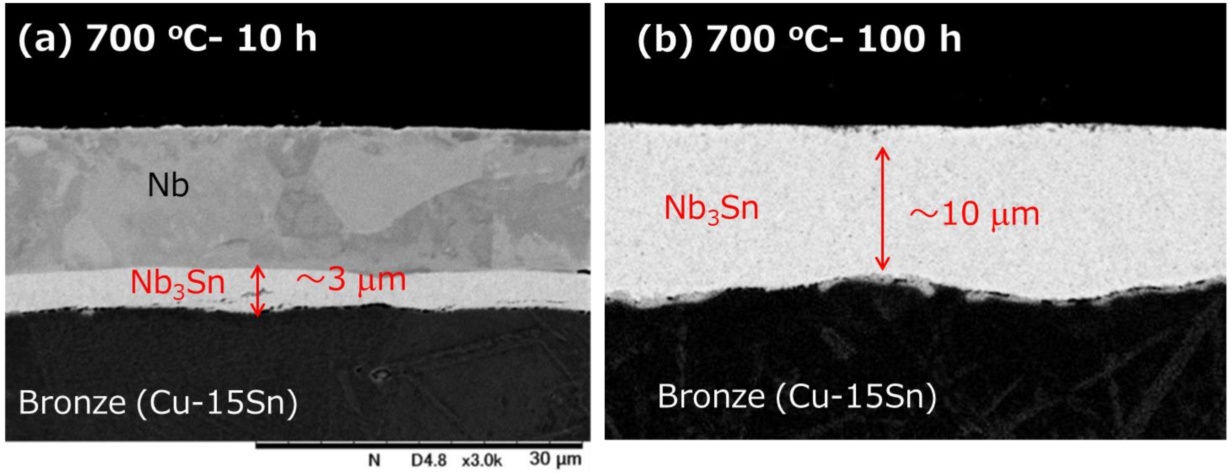


A. Kikuchi: Nb_3Sn thin film/layer via bronze route

Discovered Effect of Cu in 1967

Bypass Route for Direct Forming of Nb_3Sn Phase at low temperature diffusion reaction. (*Tachikawa Method*)

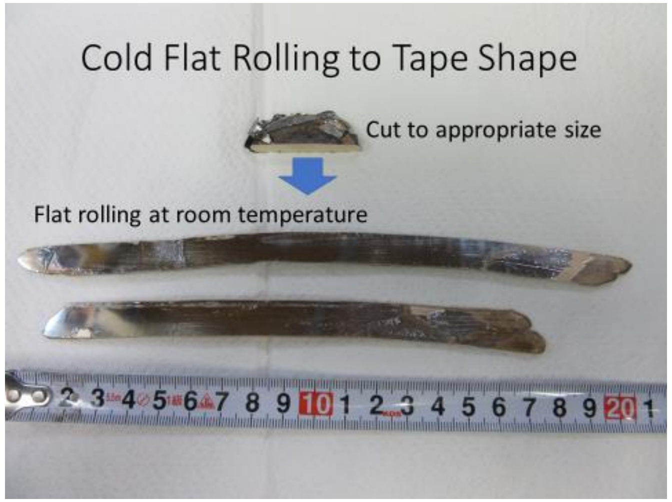


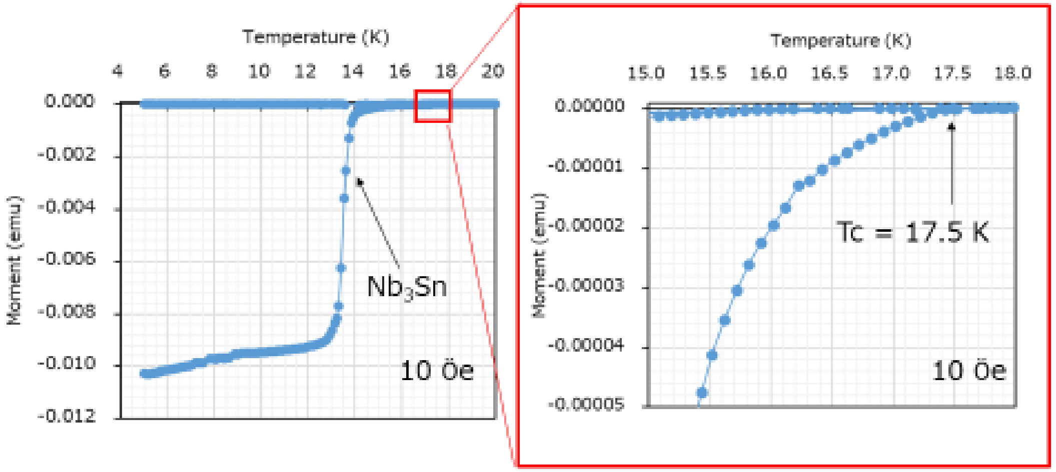


Full Reacted at 700 °C for 100 h

Method for Nb_3Sn wire

Composite material





R. Calaga: Nb_3Sn: towards machine

- Accelerator compatibility requires dealing with real world mess. So Nb3Sn needs an "industrialization" break-through
- Its applications could/should be decoupled from bulk-Nb (starting with the substrate)
- Think special applications
  - Higher frequencies (s/c-band), higher quench fields, HOM couplers
- Think cheap fabrication techniques
  - Machining/3D printing of cheaper-Nb, Cu, Al….
- One day in the far future, we might even dream of in-situ coating of Nb3Sn inside existing SC-accelerators

SRF Accelerator "Landscape"

	Some Examples	Frequencies [MHz]	Voltage [MV/m]	?
Circular colliders & storage rings	LHC, FCC, KEKB, CESR, Light sources	350-500, 800	5 – 15	
Linear Colliders & FELs	XFEL, LCLS2, ILC	1300, 3900	20-35	
High Intensity	SNS, ESS, PIPII	650-800	7 – 20	
Nuclear Physics	FRIB, HIE-ISOLDE, ATLAS..	~100-400	6 – 10, 20	
ERLs & RLs	CEBAF, Test facilities, e-cooling	700, 1300	15-20	
Special Applications	Crab/Deflecting cavities, Medical	400, 3900	~25	
Compact/cheap e-accelerators	Studies	600-800, 1300?	~10	

3

**Note: By no mean comprehensive but some qualitative examples

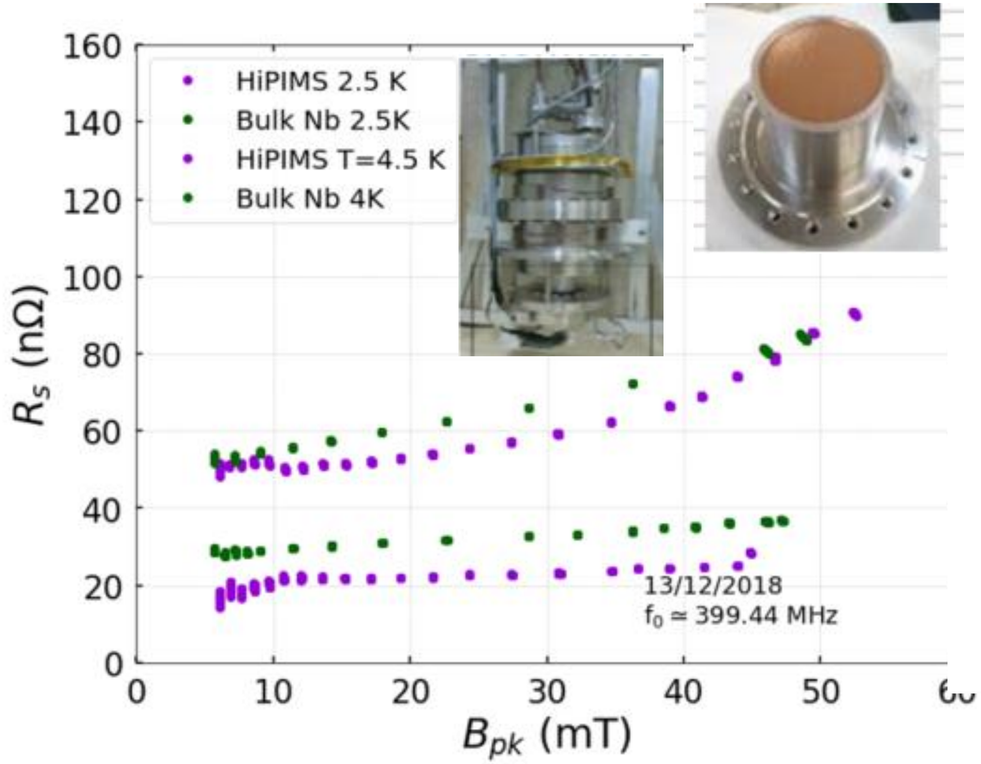
Voices from accelerator people, instead of thin film people themselves

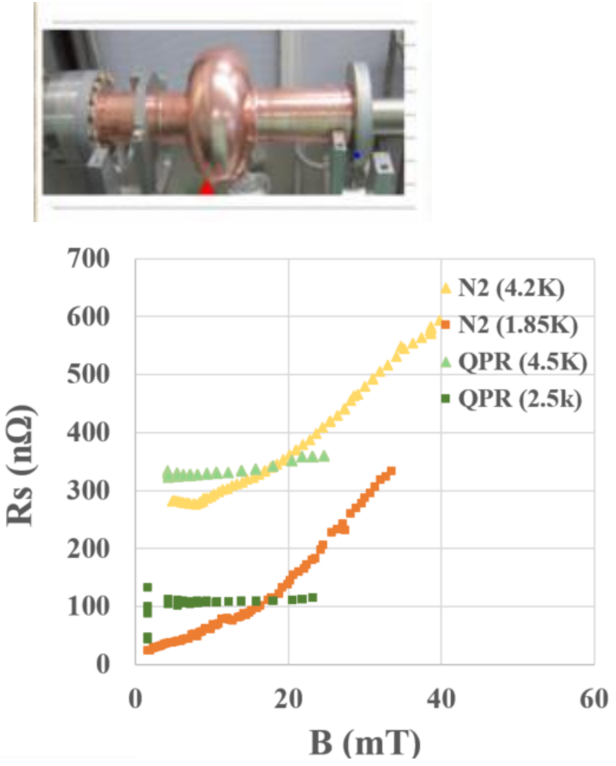
Session 4: How to predict SRF performance without building an entire cavity

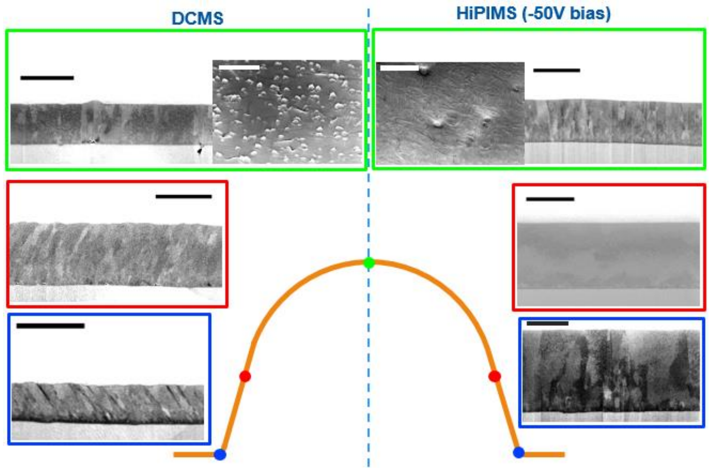
HIPIMS from QPR to 1.3GHz cavities (10'+8')	*Lorena Vega Cid*
500/1-001 - Main Auditorium, CERN	11:00 - 11:18
Predicting SRF Performance using muSR and betaNMR (10'+8')	*Edward Thoeng*
500/1-001 - Main Auditorium, CERN	11:18 - 11:36
RF local magnetometry (10'+8')	*Steven Anlage*
500/1-001 - Main Auditorium, CERN	11:36 - 11:54
Predicting SRF performance PCT (10'+8')	*Thomas Proslier*
500/1-001 - Main Auditorium, CERN	11:54 - 12:12
Local magnetometry (10'+8')	*Daniel Turner*
500/1-001 - Main Auditorium, CERN	12:12 - 12:30

Quadrupole Resonator (**QPR**), Muon Spin Roatation and Relaxation (**muSR**), beta detected nuclear magnetic resonance (**beta-NMR**), RF local magnetometry, point contact tunneling (**PCT**), vibrating sample magnetometry (**VSM**), local DC magnetometry with 3rd harmonics, field penetration measurements

Lorena Vega – HIPIMS from QPR to 1.3 GHz cavities







HiPIMS technique allows to achieve denser layer in all the orientations.
This technique may still need specific optimization for the cavity geometry

HiPIMS sample showing comparable performance to bulk niobium <u>in terms of Q-slope</u>

✓When applying the same coating technique to 1.3 GHz cavities the RF performance is not as good as expected.
✓Efforts should be put on:

Specific optimization of the coating technique for the cavity geometry.
Have good substrates (seamless cavities with thermal mapping system).

Edward Thoeng – Predicting SRF Performance using muSR and betaNMR

LE-musR: 120°C bake study with LE-muSR @ PSI[3]
limited to 30 mT (low-field)

beta-NMR Probe

Implanted low energy radioactive Li-8 beam

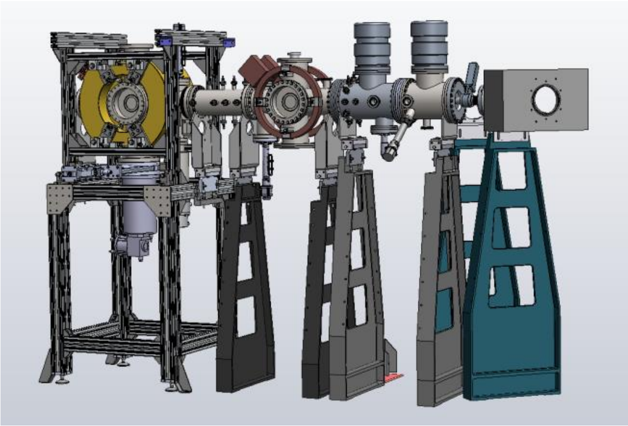
Field || sample: currently 24 mT – 200 mT after upgrade

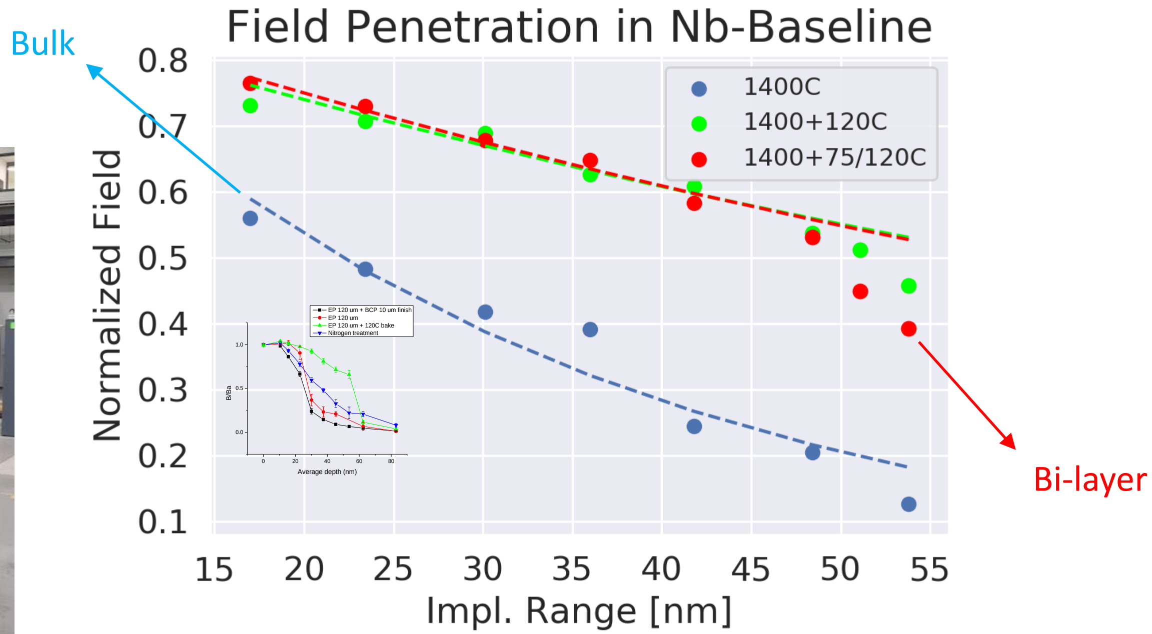
Comparison with LE-muSR

Low-energy → **Surface & interface sensitive** nm-scale

Heavier ions (vs muons) → **Larger magnetic rigidity** at high-field

HV deceleration [existing] → **Depth resolved** studies





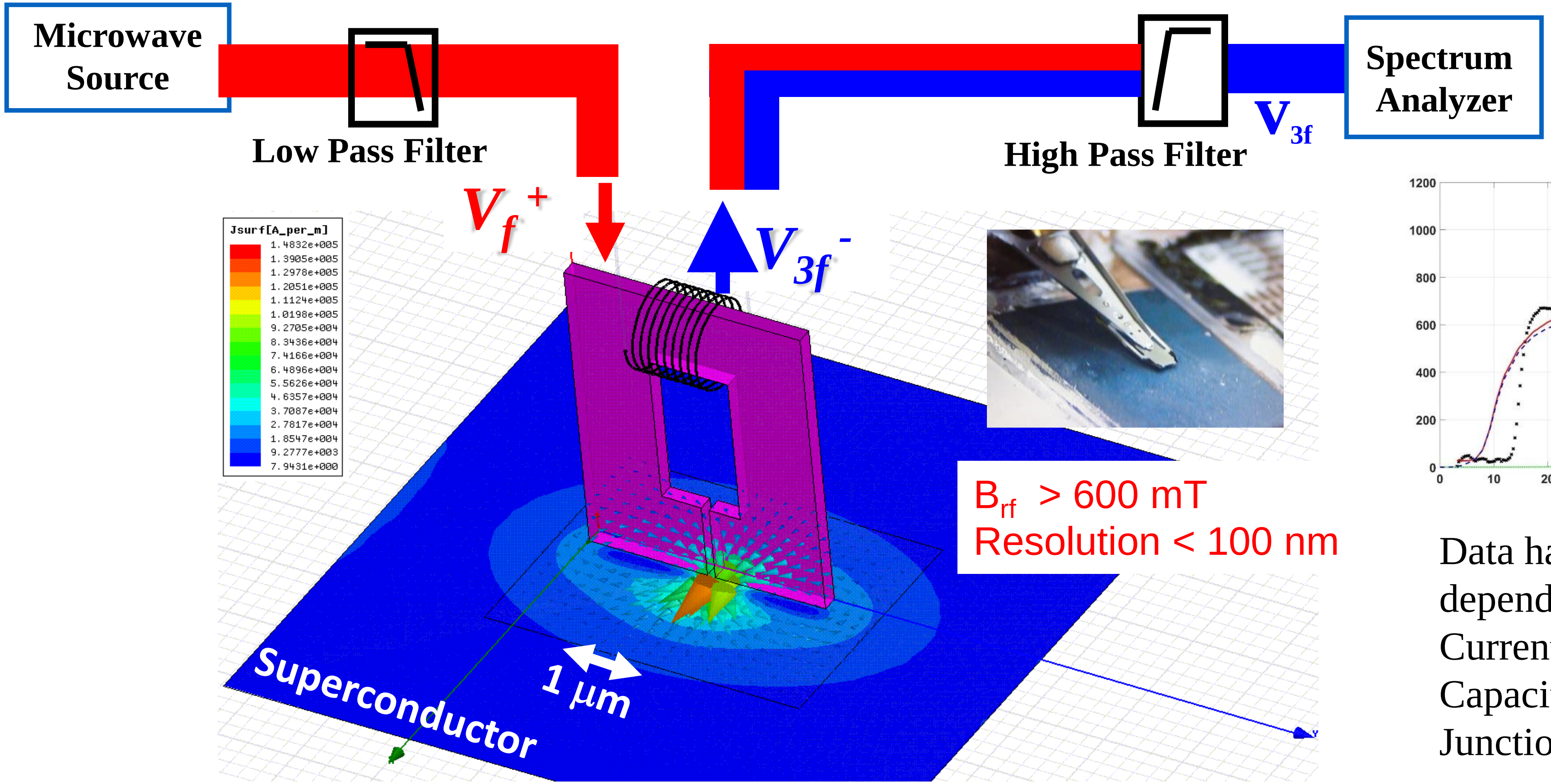
First betaNMR experiment on SRF materials – Confirmation of low energy muSR results

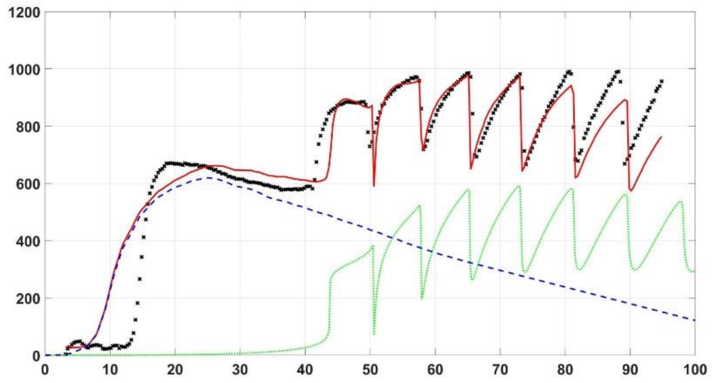
Steven Anlage – RF Local Magnetometry

Objective: Identify microscopic defects that cause breakdown of SRF cavities

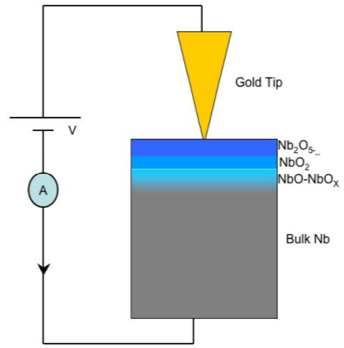
Method:
1) **Examine coupons with intense, localized B_{RF} in the superconducting state**
2) **Measure locally-produced harmonic generation from defects**
3) **Scan the probe and image the response**

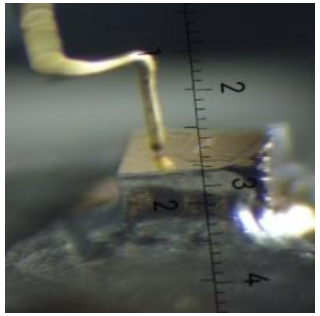
Ultimate goal is to map the surface resistance compare to theoretical models and relate to surface structure

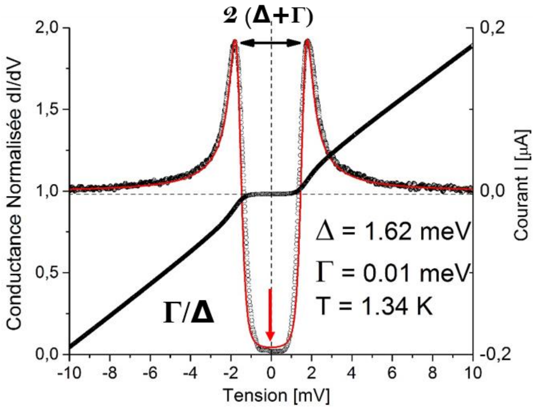




Data has been fitted with a time dependent GL model and Current Driven Resistively and Capacitively Shunted Josephson Junctions (RCSJ) model

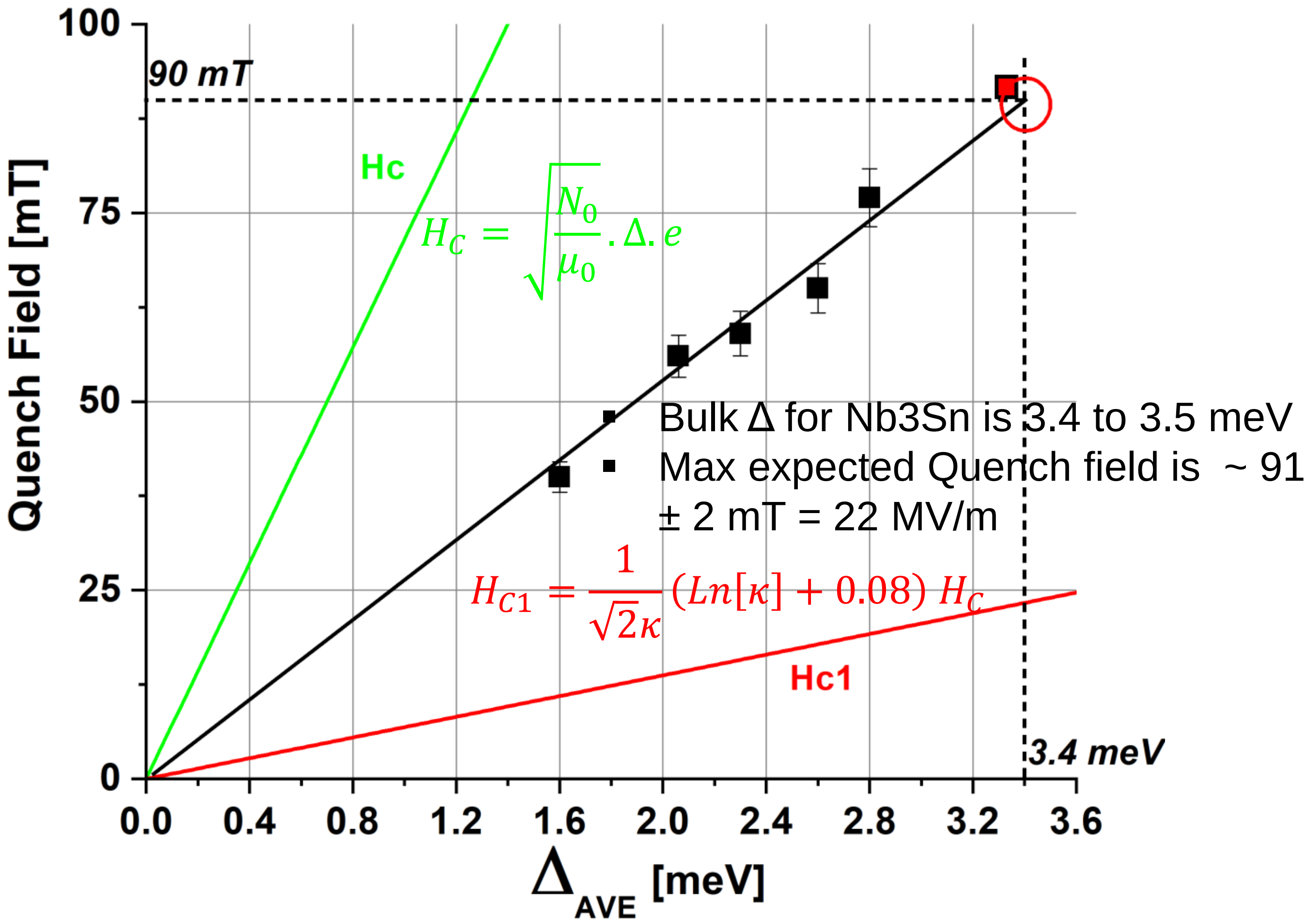






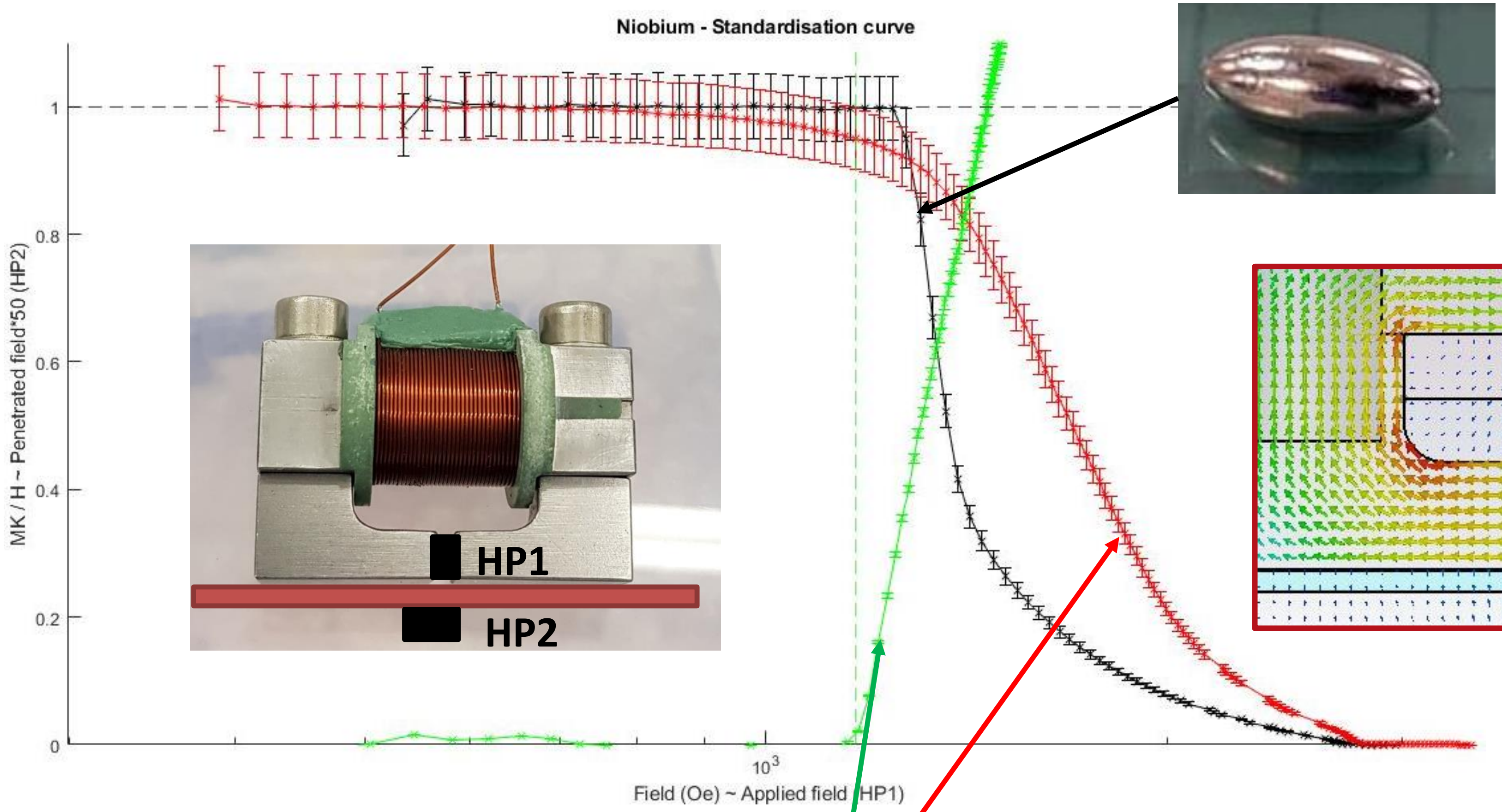
- Measure the fundamental superconducting parameters:
  Δ, T_C, H_{C2}
- Measure non-ideal signature: Γ.
- Shape of the DOS give clues to microscopic origins: *Proximity effect, magnetic impurties, deleterious phases*.
- Direct correlation to SRF cavity performances.
- Cartography.

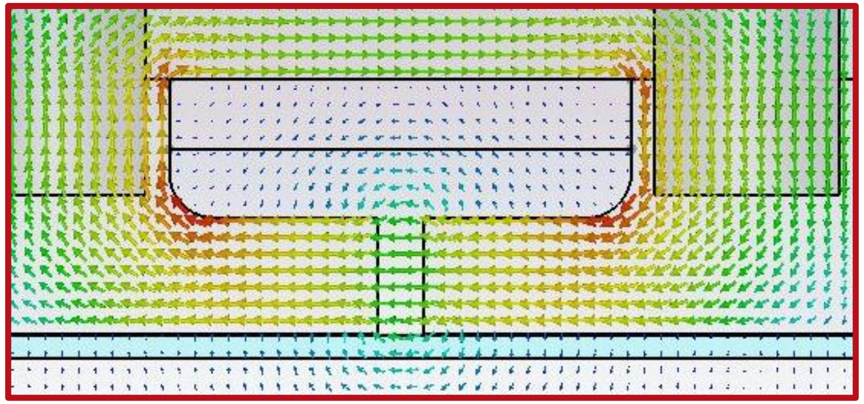
Nb3Sn - Quench field vs Average Gap

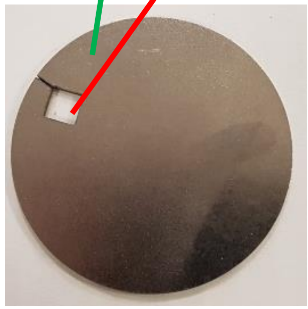


- Linear dependence of Emax on the average surface gap H_{SH}~3.5 times the H_{C1} but why this gap dependence? Roughness, effective penetration depth?

D. Turner – Local Magnetometry







Field penetration experiment, Daresbury Laboratory

- 50 mm disk
- H_{fp} (4.2 K) = 117.3 mT ± 1.5 %
- H_{fp} (0 K) = 147.8 mT ± 1.5 %

VSM magnetometer

- Ellipsoid: H_{vp}(4.2 K) = 127.5 mT
  - Demagnetization factor, 0.87
  - H_{c1}(4.2 K)= 146.6 mT
  - H_{c1}(0 K)= 184.6 mT

THANKS TO ALL CONTRIBUTORS FOR THE HIGH QUALITY TALKS