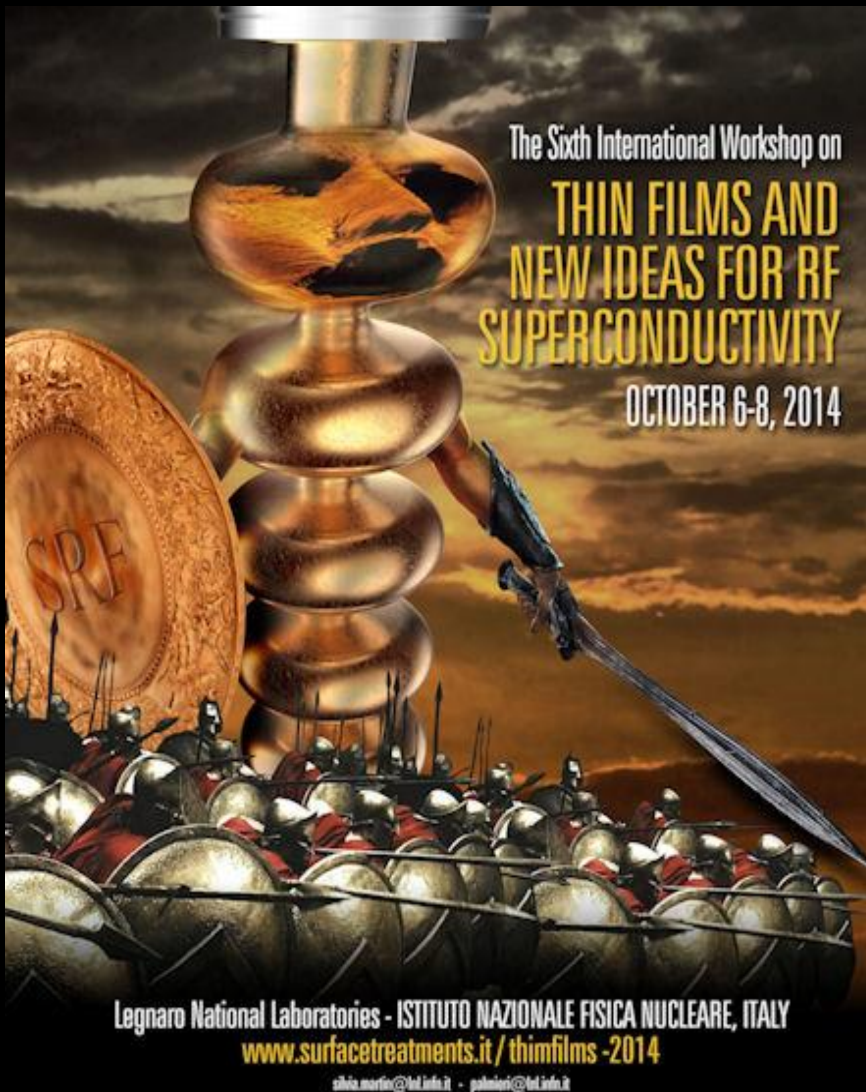
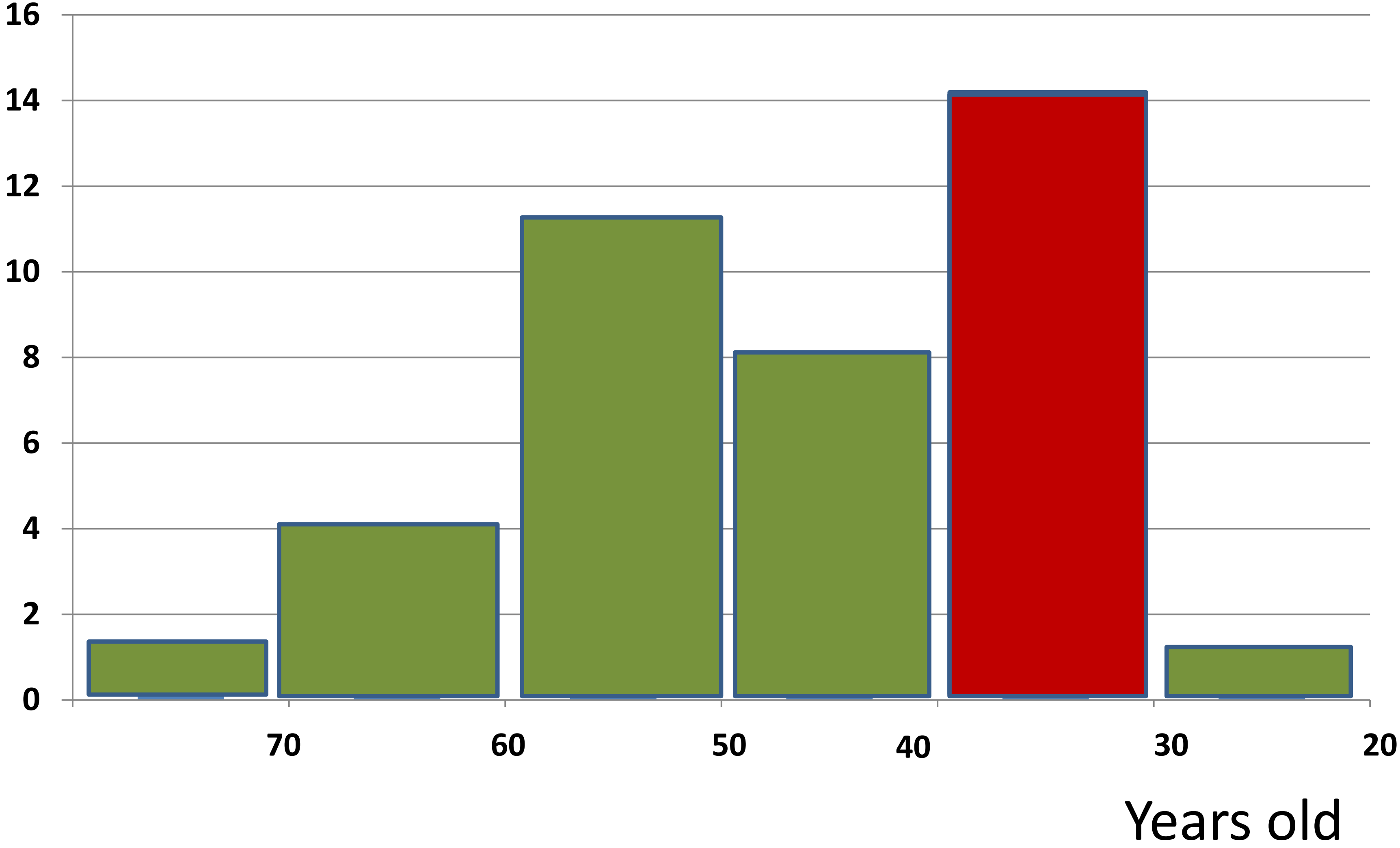


Report on ***«The 6° Thin film and New Ideas»*** Workshop

Enzo Palmieri

INFN-LNL
University of Padua

Age of Partecipants




in Surface Treatments f...
THIN FILMS WORKSHOPS
Enzo Palmieri
www.surfacetreatments.it/thinfilms-2014/
Google
thinfilms
and NEW IDEAS for SRF
The Workshop
General Information
Application Forms
Videos & Photos
Workshop AIM
Workshop Program
and Proceedings
List of Partecipants
The Sixth International Workshop on
THIN FILMS AND
NEW IDEAS FOR RF
SUPERCONDUCTIVITY
cetreatments.it/thinfilms-2014/index.asp?section=9

Coffee Break (10:40 - 11:10)

Multilayers and Gurevich Model

(Chairman: Larry Phillips)

- Maximum screening fields and the optimum parameters of superconducting multilayers for resonator cavities (Alex Gurevich - 30')
- Multilayer Approach to Increase the Performance of SRF Accelerating Structures beyond Bulk Nb (Anne-Marie Valente-Feliciano - 30')
- Tests of the Gurevich model toward larger field gradients in SRF cavities (Rosa Alejandra Lukaszew - 40')
- Open Discussion (Chair: Larry Phillips - 30')

Lunch (13:20 - 14:30)

NIOBIUM DEPOSITION: STATUS OF ART

(Chairman: Walter Venturini)

- Development of thin films for superconducting RF cavities in ASTeC (Oleg Malishev - 30')
- Porosity of Nb magnetron sputtered thin films and dependence on sputtering parameters (Hanna Skliarova - 30')

Coffee Break (10:40 - 11:10)

Multilayers and Gurevich Model

(Chairman: Larry Phillips)

▼ Maximum screening fields and the optimum parameters of superconducting multilayers for resonator cavities (Alex Gurevich - 30')

Speaker: Alex Gurevich - Old Dominion University | **Duration:** 30 min.

Abstract
Alex Gurevich, It is shown that multilayer coating can screen the applied field above the superheating fields of both the superconducting layers and the Nb substrate. There is an optimum multilayer thickness for which the breakdown field at which the multilayer remains in the vortex-free Meissner reaches maximum. It is shown that a dirty layer about the London penetration depth thick at the non-structured Nb surface can increase the superheating field of up to 290 mT. Growing optimized multilayer structures of Nb3Sn or iron pnictides or forming a dirty layer at the surface of the Nb resonator cavities for particle accelerators OFFER opportunities to increase the peak accelerating electric fields above 100 MV/m.

Slides

slideshare

Videos

viewfile

Future CERN projects and their technological challenges

By Dr. José Miguel JIMENEZ
Technology Department Head, CERN

CERN Medium – Long Term Strategy

European Strategy for Particle Physics

Europe's top priority should be the exploitation of the full potential of the LHC, including the high-luminosity upgrade of the machine and detectors with a view to collecting ten times more data than in the initial design, by around 2030.
This upgrade programme will also provide further exciting opportunities for the study of flavour physics and the quark-gluon plasma.

and this is what CERN Medium Term Plan is implementing!

CERN Medium – Long Term Strategy

European Strategy for Particle Physics

- **High-priority large-scale scientific activities**

- d) To stay at the forefront of particle physics, Europe needs to be in a position to propose an ambitious post-LHC accelerator project at CERN by the time of the next Strategy update, when physics results from the LHC running at 14 TeV will be available.

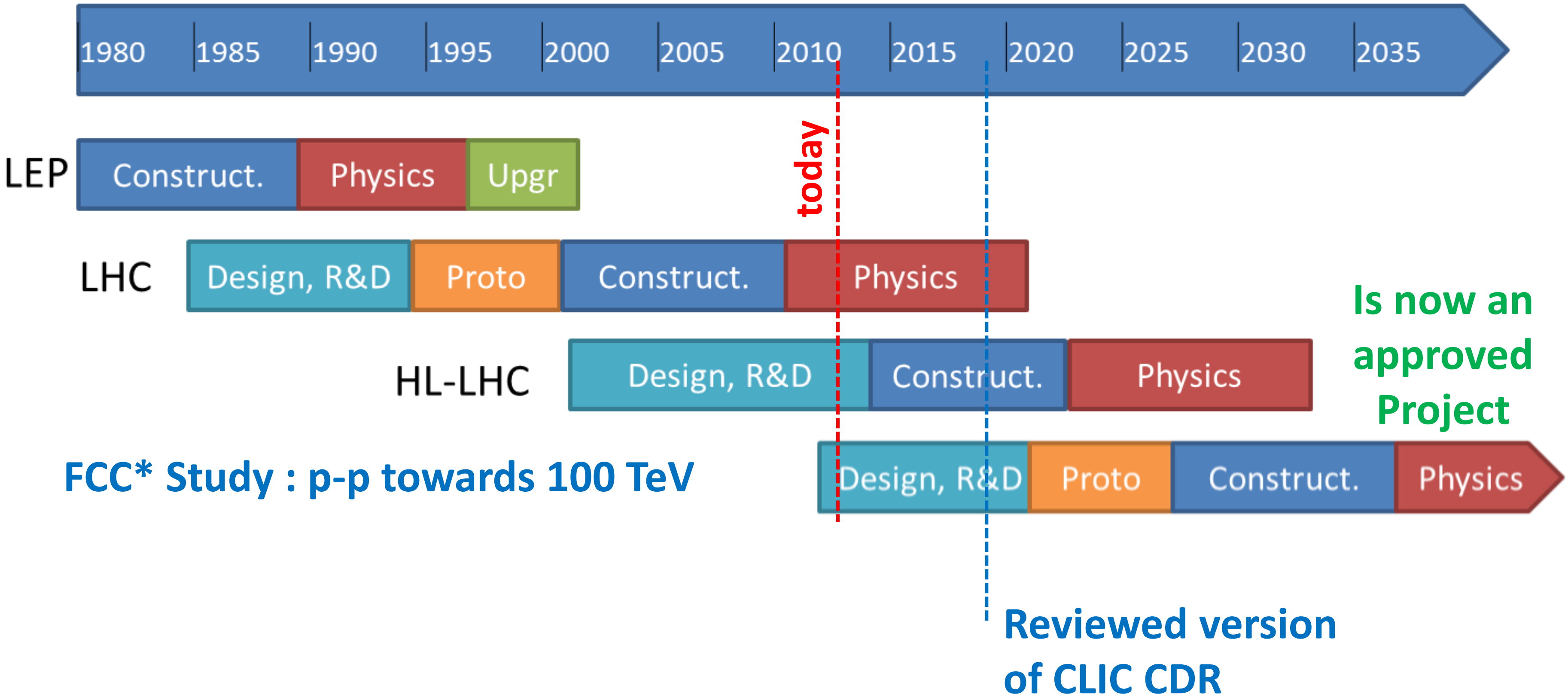
CERN Medium – Long Term Strategy

European Strategy for Particle Physics

- **High-priority large-scale scientific activities**

CERN should undertake design studies for accelerator projects in a global context, with emphasis on proton-proton and electron-positron high energy frontier machines. These design studies should be coupled to a vigorous accelerator R&D programme, including high-field magnets and high-gradient accelerating structures, in collaboration with national institutes, laboratories and universities worldwide.

European Strategy: "CERN should undertake design studies for accelerator projects in a global context, with emphasis on ***proton-proton*** *and electron- positron* ***high-energy frontier machines.****"*



***FCC: Future Circular Colliders**

"CERN should undertake design studies for accelerator projects in a global context, with emphasis on proton-proton and ***electron-positron high-energy frontier machines."***

Technological Challenges

- **HL-LHC and future projects need R&D now!**

- Future generation of accelerators will need new concepts and technological breakthroughs, **scaling is NOT an option**:
  - To provide the required reliability;
  - To keep costs within acceptable levels.

Future Circular Collider Study SC-RF Systems and Opportunities

Erk Jensen/CERN

Many thanks to: M. Benedikt, A. Butterworth, O. Brunner, R. Calaga, S. Claudet, R. Garoby, F. Gerigk, P. Lebrun, E. Montesinos, D. Schulte, E. Shaposhnikova, I. Syratchev, M. Vretenar, J. Wenninger

FCC Study – Scope (1)

- A conceptual design study of **options for a future high-energy frontier circular collider** at CERN for the post-LHC era shall be carried out, implementing the request in the 2013 update of the European Strategy for Particle Physics.

- The design study shall be **organised on a world-wide international collaboration** basis under the auspices of the European Committee for Future Accelerators (ECFA) and shall be available in time for the next update of the European Strategy for Particle Physics, foreseen by 2018.

FCC Study – Scope (2)

- The **main emphasis** of the conceptual design study shall be the long-term goal of a **hadron collider with a centre-of-mass energy of the order of 100 TeV in a new tunnel of 80 - 100 km circumference** for the purpose of studying physics at the highest energies.

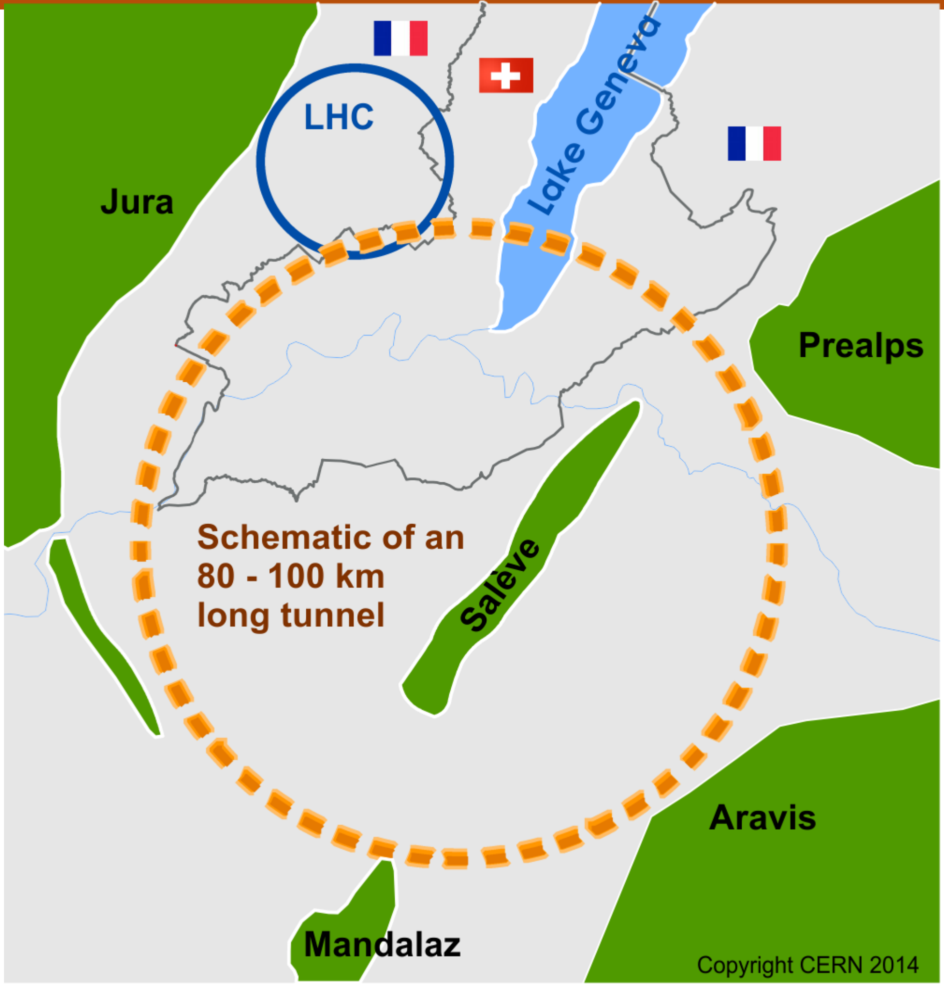
FCC Study – Scope (3)

Forming an international collaboration to study:

- ***pp*-collider (*FCC-hh*)** → defining infrastructure requirements

~16 T ⇒ 100 TeV *pp* in 100 km
~20 T ⇒ 100 TeV *pp* in 80 km

- ***e^+e^-* collider (*FCC-ee*)** as potential intermediate step
- ***p-e* (*FCC-he*) option**
- **80-100 km infrastructure** in Geneva area



SC RF R&D Opportunities

- The area of R&D identified as key for the FCC is the study and development of ***advanced coating techniques***. Cu cavities with sputtered Nb coatings were used at LEP, are used in LHC and will be used in HIE-ISOLDE. The present-day performance of these cavities in terms of maximum accelerating gradient and Q_0 is moderate compared to advanced bulk Nb cavities, whereas clear advantages arise from the good thermal conductivity and stability of Cu.

- **The above examples demonstrate that there is still exciting physics out there to be discovered and technologies to be developed. The European Strategy encourages us to undertake this R&D.**

Maximum screening field and the optimum parameters of superconductivity multilayers for resonator cavities

Alex Gurevich

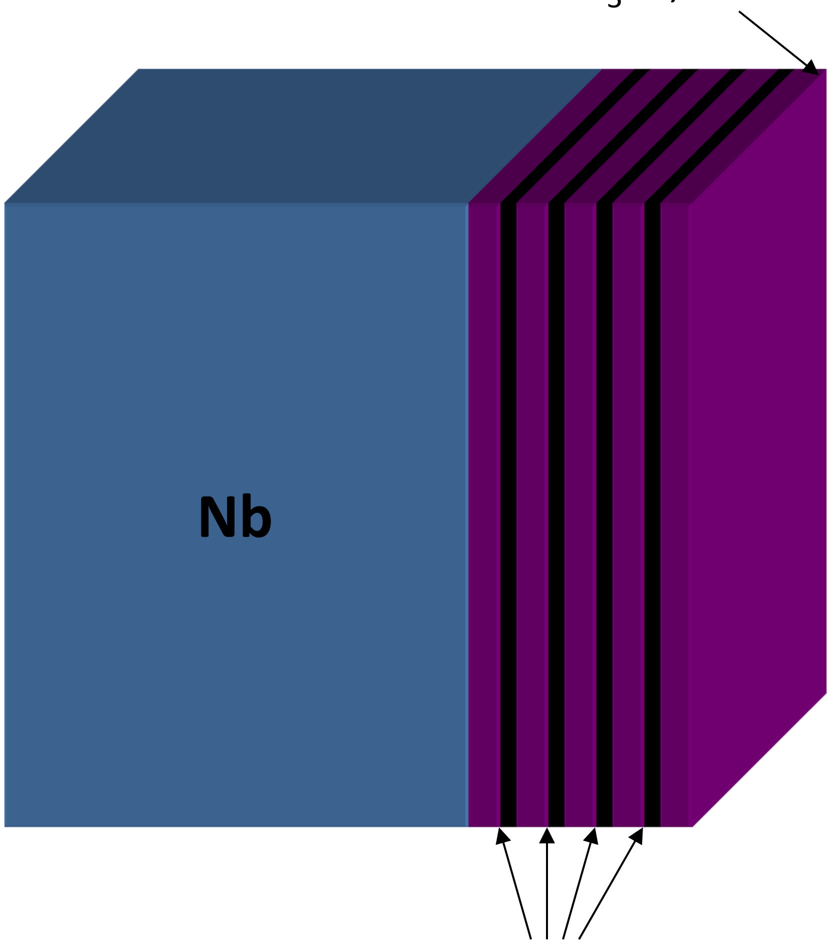
Old Dominion University,
Department of Physics and Center for Accelerator Science,
Norfolk, VA 23529, USA

Supported by the US Department of Energy, HEP under grant No. DE-SC0010081

The Sixth International Workshop on THIN FILMS AND NEW IDEAS FOR SRF
October 6 –8, 2014 Legnaro National Laboratories (Padua) ITALY

Multilayer coating

AG, APL. 88, 012511 (2006)



Multilayer coating of SC cavities: alternating SC and I layers with $d < \lambda$

Magnetic screening of the Nb cavity without vortex penetration

No thermodynamically stable parallel vortices due to the enhancement of H_{c1} in thin films with $d < \lambda$ **(Abrikosov, 1964)**

$$H_{c1} = \frac{2\phi_0}{\pi d^2}\left(\ln\frac{d}{\xi} - 0.07\right)$$

The breakdown field could be increased up to the superheating field H_s of the coating: 450 mT for Nb_3Sn

The idea has caused a lot of excitement and misinterpretations ($H_{c1} = 0$, H_{c1} is not important, H_s is reduced not increased, "unmanageable" dissipation, etc, **S. Posen et al., 2014**)

Recent progress

- Experimental evidences of the enhancement of the parallel H_{c1} in thin films

L. Civale, T.K. Worthington, A. Gupta, Phys. Rev. B 48, 7576 (1993).

C. Antoine, et al Phys. Rev. ST-AB 13, 121001 (2010).

T. Tajima, et al. J. Phys. Conf. Ser. 234, 012043 (2010); AIP Conf. Proc. 1435, 297 (2012).

DB Beringer, C Clavero, T Tan, XX Xi, WM Roach, RA Lukaszew IEEE Trans. Appl. Supercond. 23, (2013)

- Increasing the high-field performance and reduction of surface resistance by a NbN overlayer

C.Z. Antoine, J.-C. Villegier, G. Martinet, APL 102, 102603 (2013).

WM Roach, DB Beringer, Z Li, C Clavero, RA Lukaszew, IEEE Trans. Appl. Supercond. 23 (2013)

Recent progress

What's next?

- Is there an optimum thickness of layers which maximizes the breakdown field? ✔

- If yes, how far can the maximum screening field H_m be increase by multilayers?
  Can the optimized H_m exceed the superheating field ? ✔

- Do we know how to select is the best layer material?
  Can we just use a dirty Nb ✔

- Are the insulating layers really necessary to protect the cavity and to suppress strong dissipation caused by local penetration of vortices at defects? ✔

Possible multilayer materials

Material	T_c (K)	H_c [T]	H_{c1} [mT]	H_{c2}[T]	λ[nm]	Δ [meV]
Nb	9.2	0.2	170	0.4	40	1.5
pnictides	30-55	0.5-0.9	30	>100	200	10-20
Nb_3Sn	18	0.54	50	30	85	3.1
NbN	16.2	0.23	20	15	200	2.6
MgB_2	40	0.43	30	3.5-60	140	2.3; 7.1
~~YBCO~~	93	1.4	10	>100	150	20

Large gap Δ (good for SRF) is usually accompanied by low H_{c1} (bad for SRF)

$$R_s = \mu_0^2 \sigma_n \lambda^3 \omega^2 \frac{\Delta}{kT} \ln\left(\frac{9kT}{4\hbar\omega}\right) e^{-\Delta/kT}$$

Very small surface resistance at $H < H_{c1}$ ($Q = 10^{10}$-10^{11})

Q drop due to vortex dissipation at $H > H_{c1}$

Nb has the highest H_{c1}

$$B_{c1} = \frac{\phi_0}{4\pi\lambda^2}\left(\ln\frac{\lambda}{\xi} + 0.5\right)$$

but not H_c:

$$B_c = \frac{\phi_0}{2\sqrt{2}\pi\lambda\xi}$$

Raise RF critical field above $H_{c1}^{(Nb)}$ using higher H_c materials which have low H_{c1}

Maximum screening field

- The maximum screening field H_m corresponds to d = d_m for which

$$H_m = \left[H_s^2 + \left(1 - \frac{\lambda_0^2}{\lambda^2}\right) H_{s0}^2\right]^{1/2}$$

H_m at the optimum thickness exceeds the bulk superheating fields of both Nb and the layer material. For $\lambda \gg \lambda_0$, practically for $\lambda > 160$ nm for a SC layer on the Nb cavity with $\lambda_0 = 40$ nm, H_m approaches the limit

$$H_m \to \sqrt{H_s^2 + H_{s0}^2}$$

Let us evaluate H_m for a ML on clean Nb with $\lambda_0 = 40$ nm and $H_{s0} = 1.2H_c = 240$ mT (the GL result for clean Nb) and different layer materials, such as Nb_3Sn, NbN, pnictides, and also dirty Nb

AG, unpublished, 2014

Estimates of H_m and d_m

- **Nb_3Sn:** $H_s = 0.84H_c = 454$ mT and $\lambda = 120$ nm (moderately dirty):

  $H_m = 507$ mT, $d_m = 1.1\lambda = 132$ nm

  doubles the superheating field of clean Nb

- **$Ba_{0.6}K_{0.4}Fe_2As_2$,** $T_c = 38$ K, $H_c = 0.9$T, $H_s = 756$ mT, $\lambda = 200$ nm

  $H_m = 930$ mT, $d_m = 1.78\lambda = 356$ nm.

  almost quadruples the superheating field of clean Nb

- **dirty Nb layer:** $H_c = 200$ mT, $H_s = 170$ mT, $l = 2$ nm, and $\lambda = \lambda(\xi_0 /l)^{1/2} = 180$ nm

  $H_m = 288$ mT, $d_m = 0.44\lambda = 79$ nm.

  20% gain as compared to $H_s = 240$ mT of clean Nb

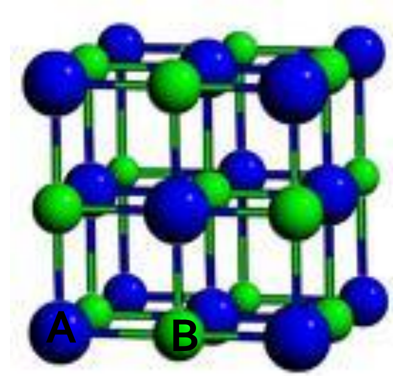
A-M Valente-Feliciano

G. Eremeev, L. Phillips, C. Reece, J. Spradlin, O. Trofimova (JLab)
A. Lukaszew (W&M)
R. Crooks (Black Labs, LLC)

Multilayer Approach to Increase the Performance of SRF Accelerating Structures beyond Bulk Nb

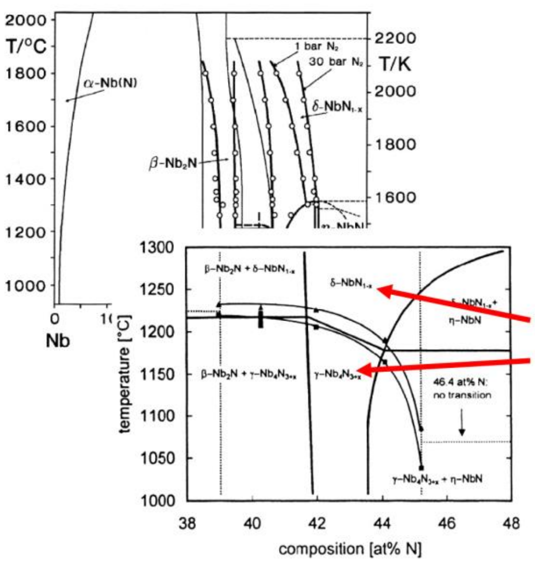
Choice of superconductor for S-I-S structures

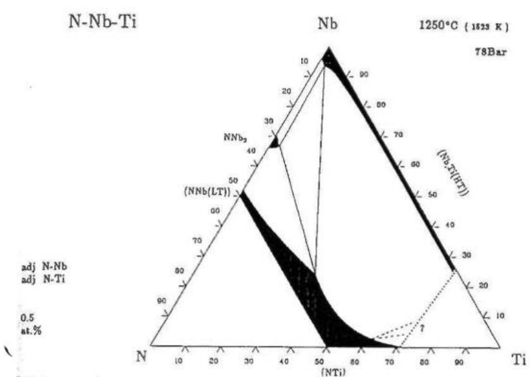
Ternary Nitride $(Nb_{1-x},Ti_x)N$ (Tc=17.3K, a= 4.341 Å)



Presence of Ti found to reduce significantly the resistivity
And facilitate formation of a pure cubic structure.
The δ-phase remains thermodynamically stable even at RT.
T_c as high as for good quality NbN, for Nb fraction (1-x)>0.5

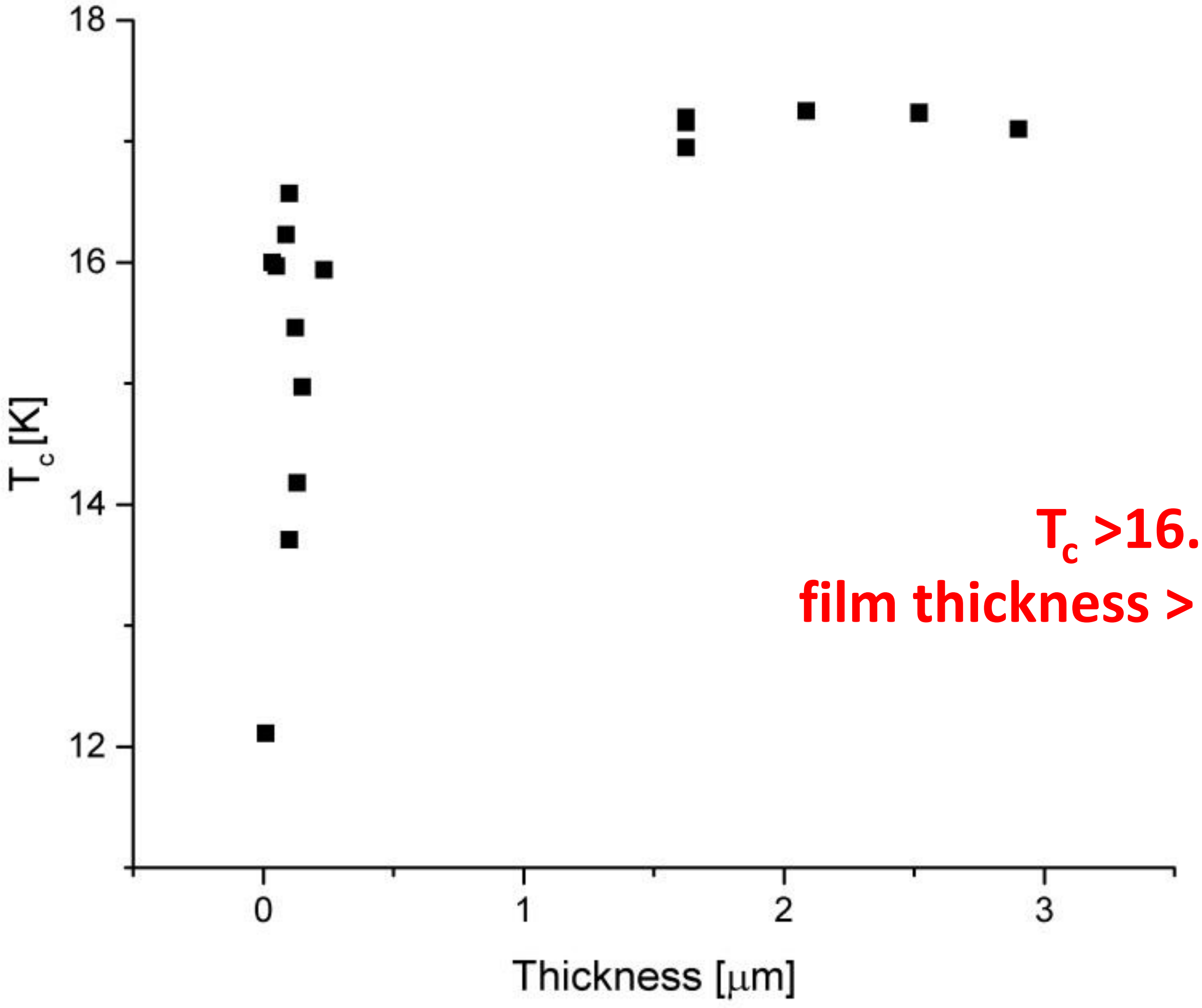
More metallic nature and better surface properties than NbN should result in better RF performance





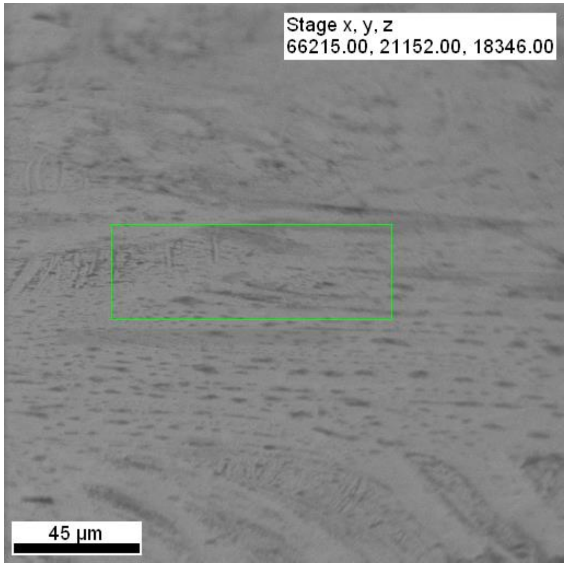
extreme hardness, excellent adherence on various substrates, very good corrosion and erosion resistance, high-sublimation temperature, and relative inertness

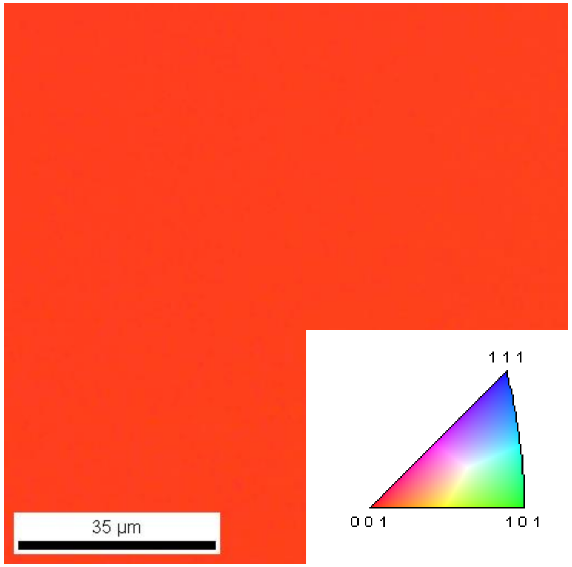
NbTiN Films – Influence of thickness on Tc

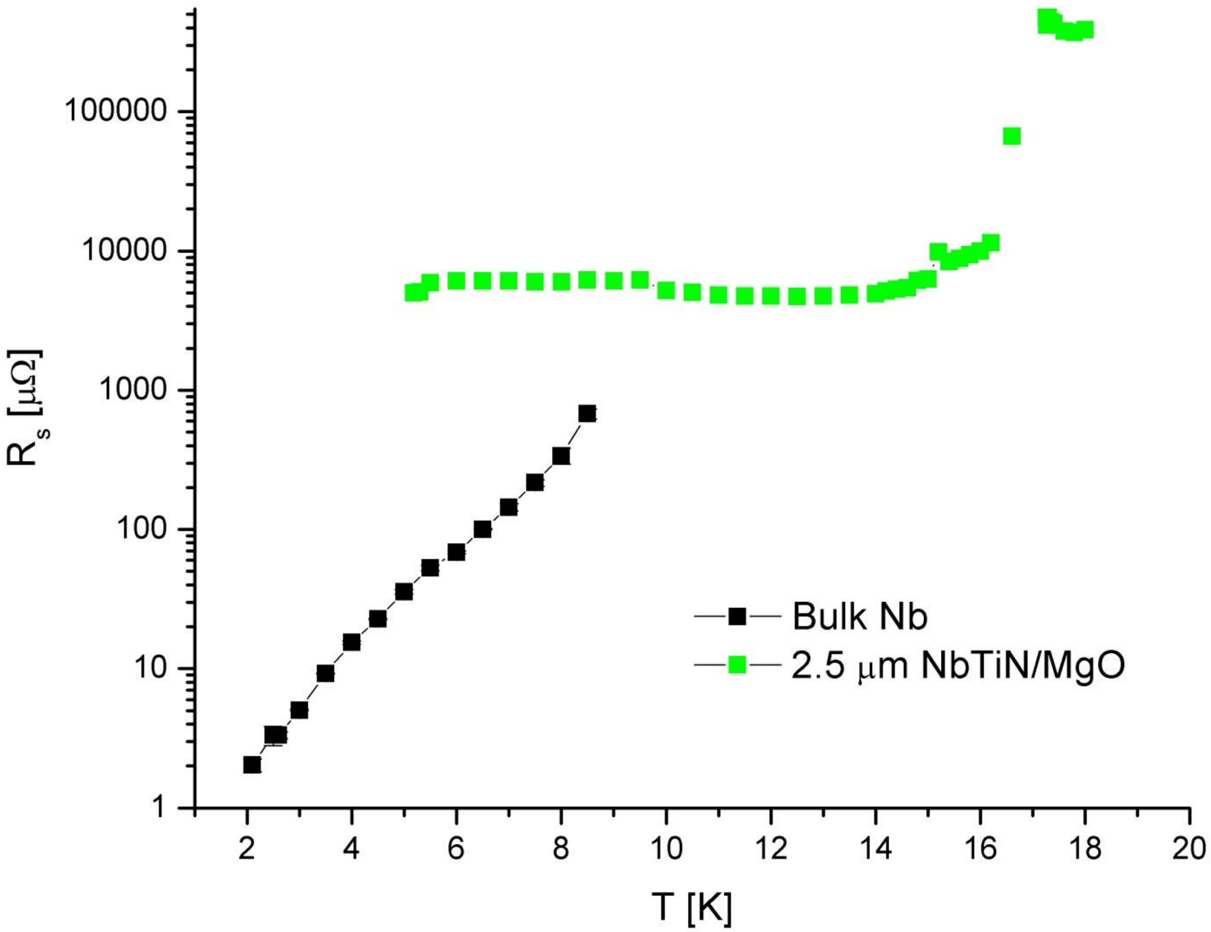


T_c >16.5 K for film thickness > 50 nm

R_s of bulk NbTiN film (2 µm)





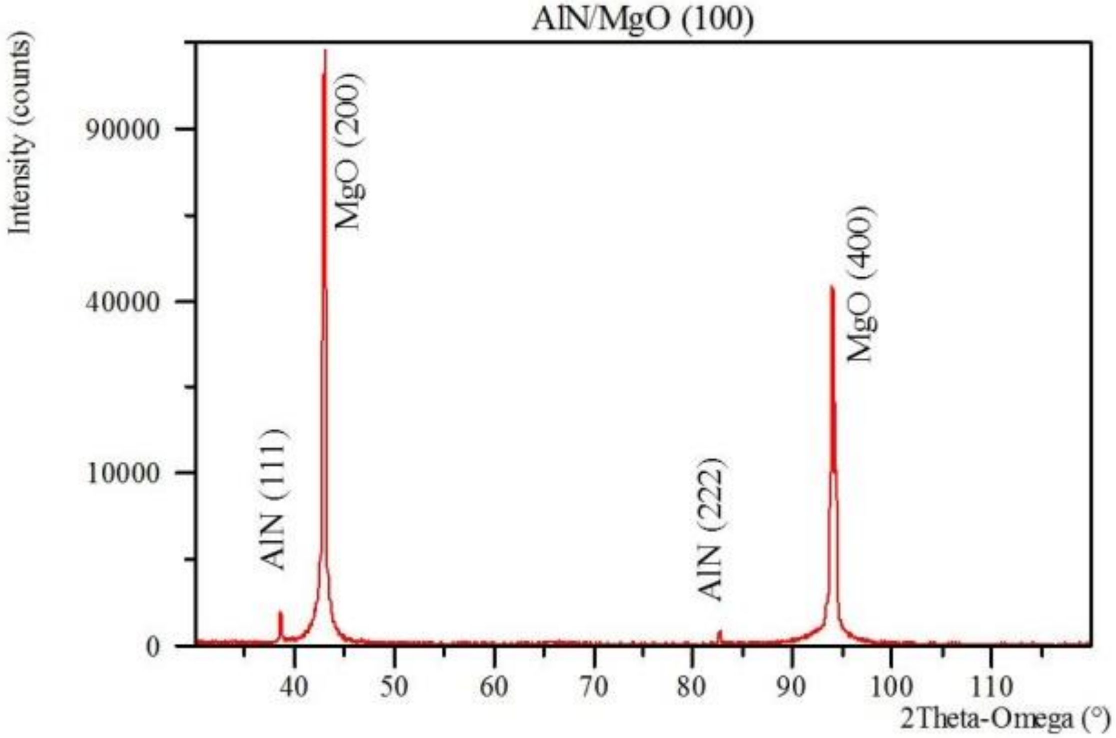


AlN Films

Good quality AlN are readily produced at 600 and 450°C by dc-reactive magnetron sputtering.
The films exhibit the cubic structure (single crystal) at 600 °C and the hexagonal structure (polycrystalline) at 450 °C

Process Conditions for AlN

N_2/Ar	0.33
Total pressure	$2x10^{-3}$ Torr
Sputtering Power	50 -100 W
Deposition rate	~ 15nm/min

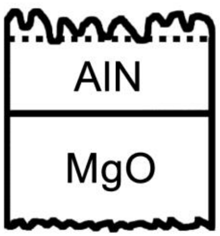


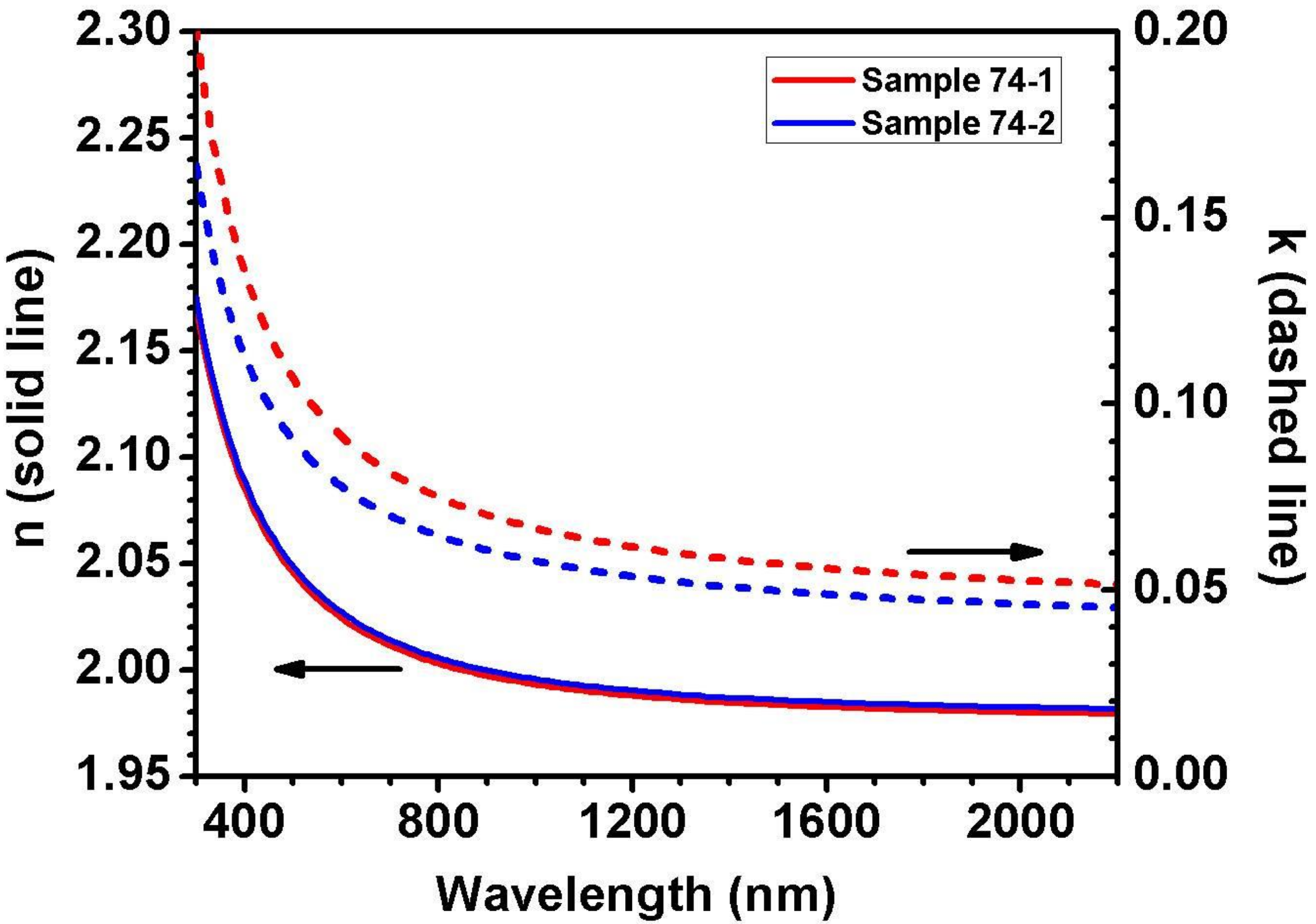
Jefferson Lab

AlN Films – dielectric behavior

At 450 °C, 30 nm AlN films exhibit dielectric properties of polycrystalline AlN films

n in the range of 1.98- 2.15

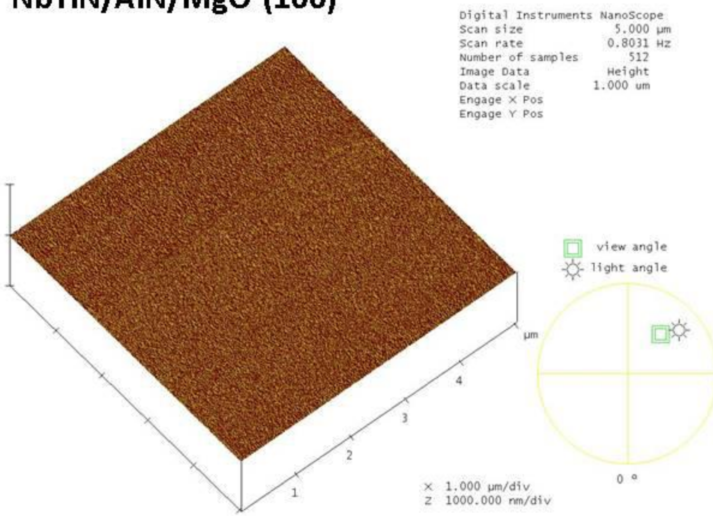




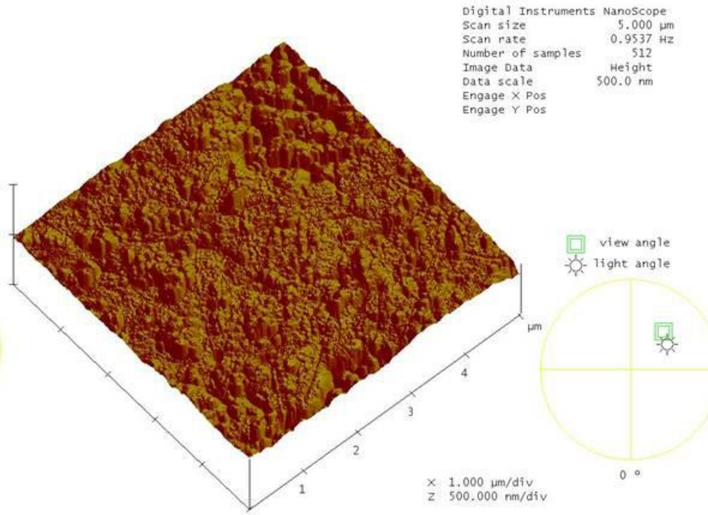
SRF Multilayer Structures Based on NbTiN

Influence of roughness & interlayer on T_c

NbTiN/AlN/MgO (100)

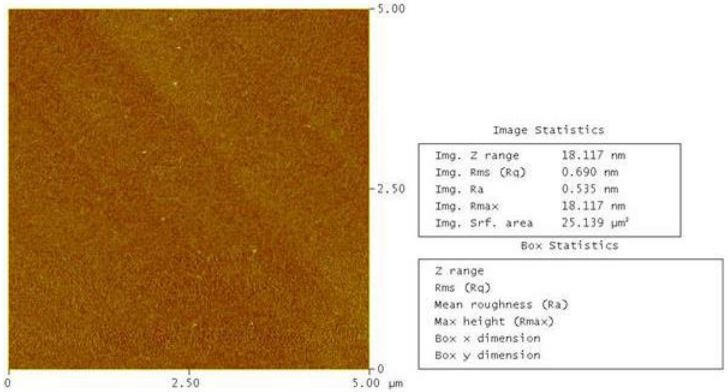


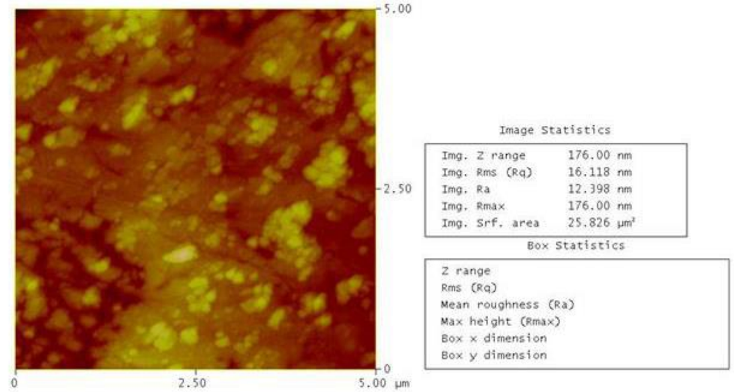
NbTiN/AlN/AlN ceramic



R_{ms}= 0.690 nm, a = 4.3455 nm

R_{ms}= 16.118 nm, a = 4.3584 nm





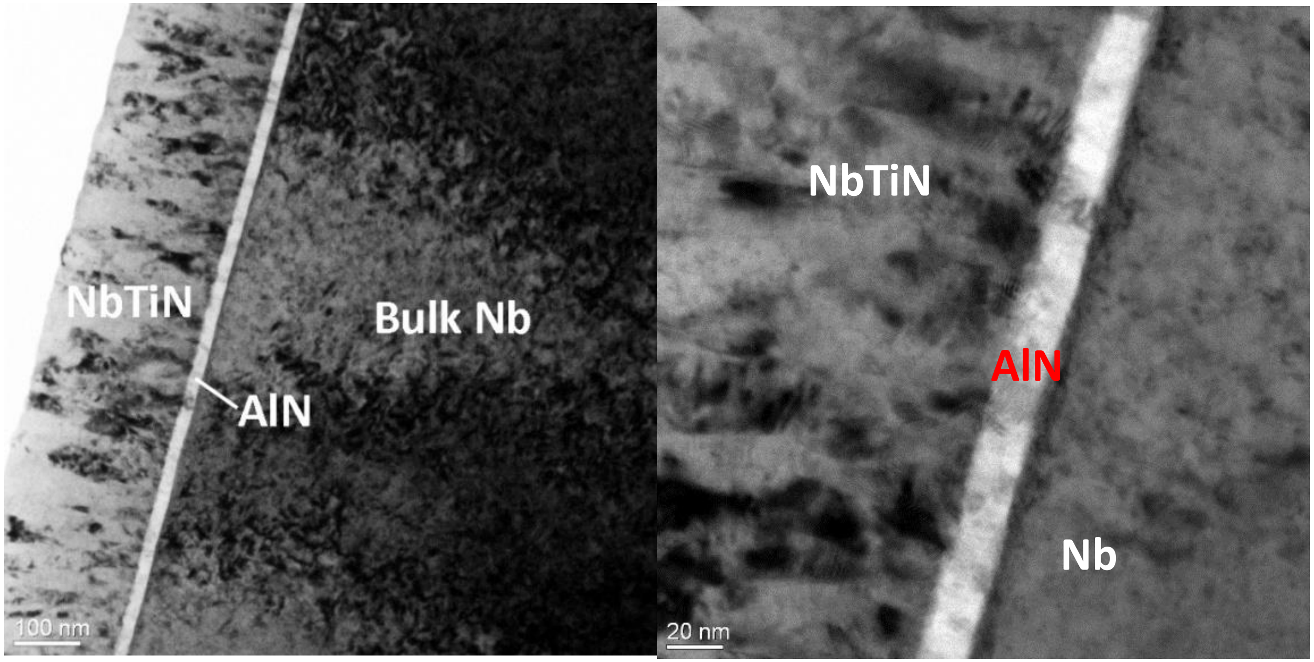
Quality of underlying AlN dictates quality of the NbTiN film

NbTiN/AlN/Nb film at 450 °C

	AlN	NbTiN
N_2/Ar	0.33	0.23
Total pressure [Torr]	$2x10^{-3}$	$2x10^{-3}$
Sputtering Power [W]	100	300
Deposition rate [nm/min]	~ 2.5	~ 18
Thickness [nm]	20	100
Tc [K]	N/A	16.9

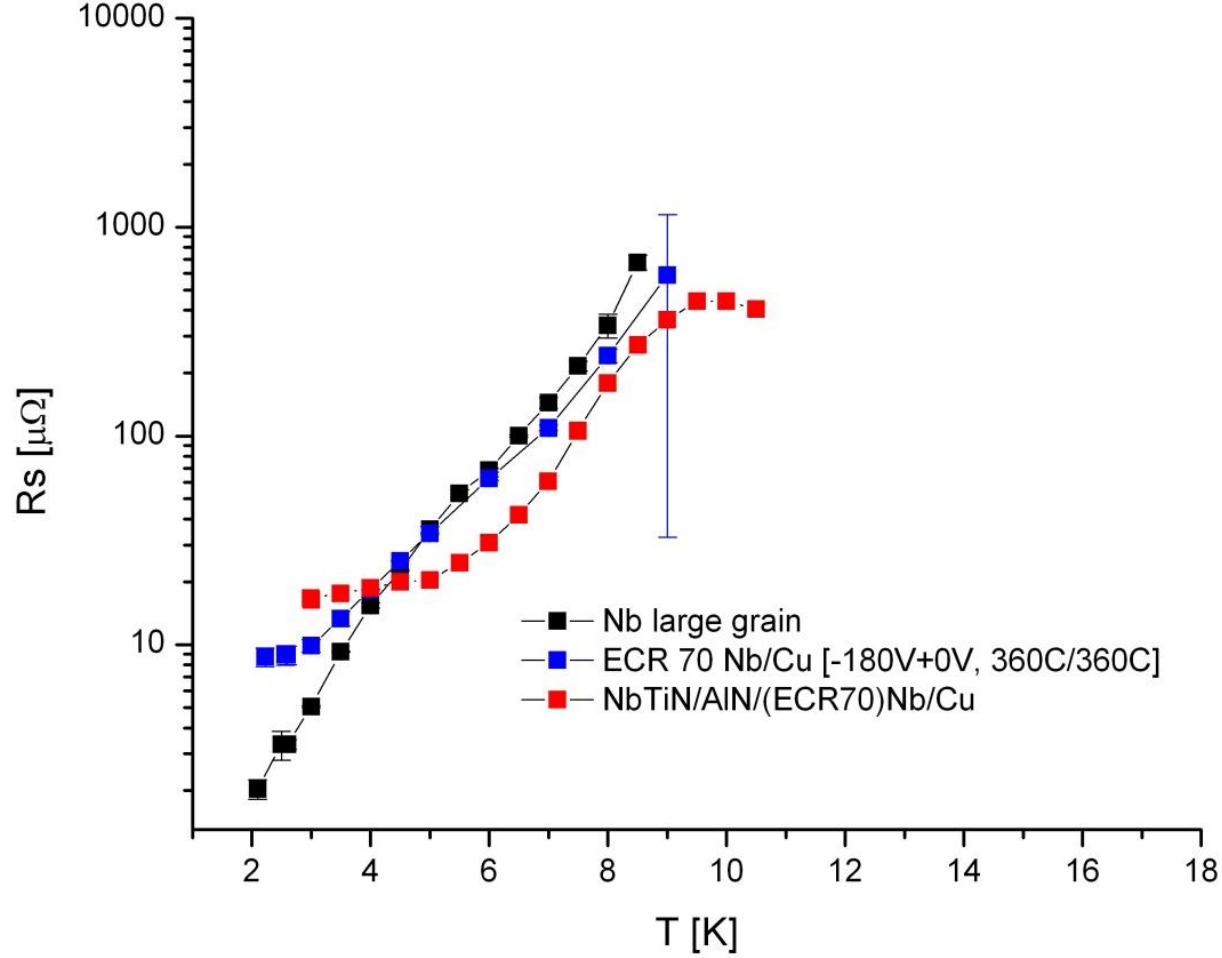
TEM cross-section (FIB cut) of NbTiN/AlN/Nb/Cu structure

Sharp interfaces

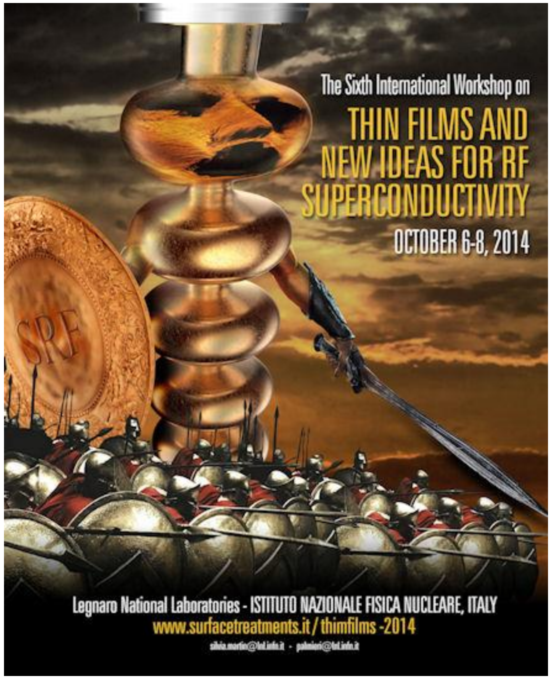


R_s of NbTiN/AlN structures on Nb surfaces

SIS structures coated at 450°C in-situ on ECR Nb/Cu film after a 24h-bake at 450°C. The samples are then annealed at 450°C for 4 hours.



Lower BCS resistance beyond 4 K for SIS coated Nb/Cu film compared to standalone film & bulk Nb. Similar effect observed for NbTiN/AlN/bulk Nb



TESTS OF THE GUREVICH MODEL TOWARD ENHANCED FIELD GRADIENTS IN SRF CAVITIES

R. A. Lukaszew, M. Burton, M. Beebe, D. B. Beringer, W. M. Roach,

College of William and Mary, Williamsburg, Virginia, USA

G. V. Eremeev, A-M. Valente-Feliciano, J. Spradlin, L. Phillips, C. Reece

Thomas Jefferson National Accelerator Facility [TJNAF], Newport News, Virginia, USA

Xiaoxing Xi,

Temple University, Philadelphia, Pennsylvania, USA

C. Clavero, LBNL

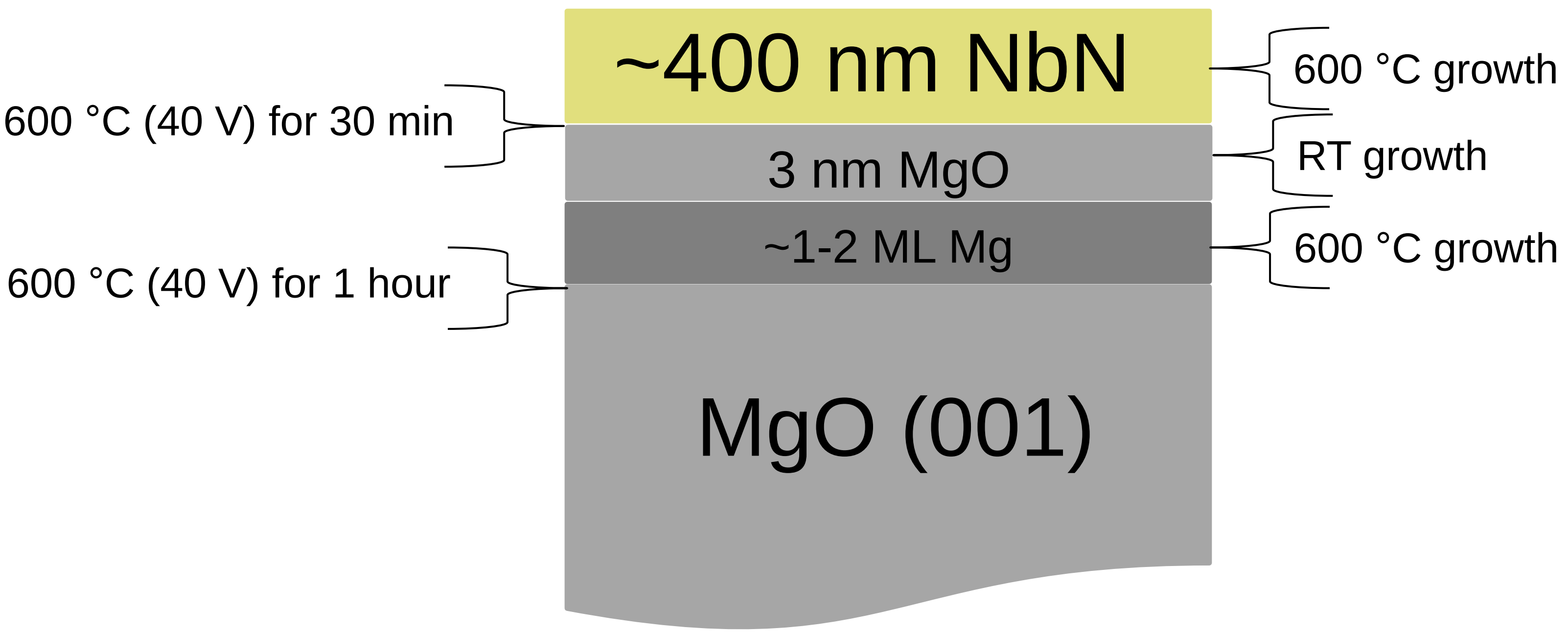
Jefferson Lab
EXPLORING THE NATURE OF MATTER

WILLIAM & MARY

Other possible SC for the SIS model

NbN, MgB_2, etc.

Growth Procedure for NbN Films
Partial Pressure Series

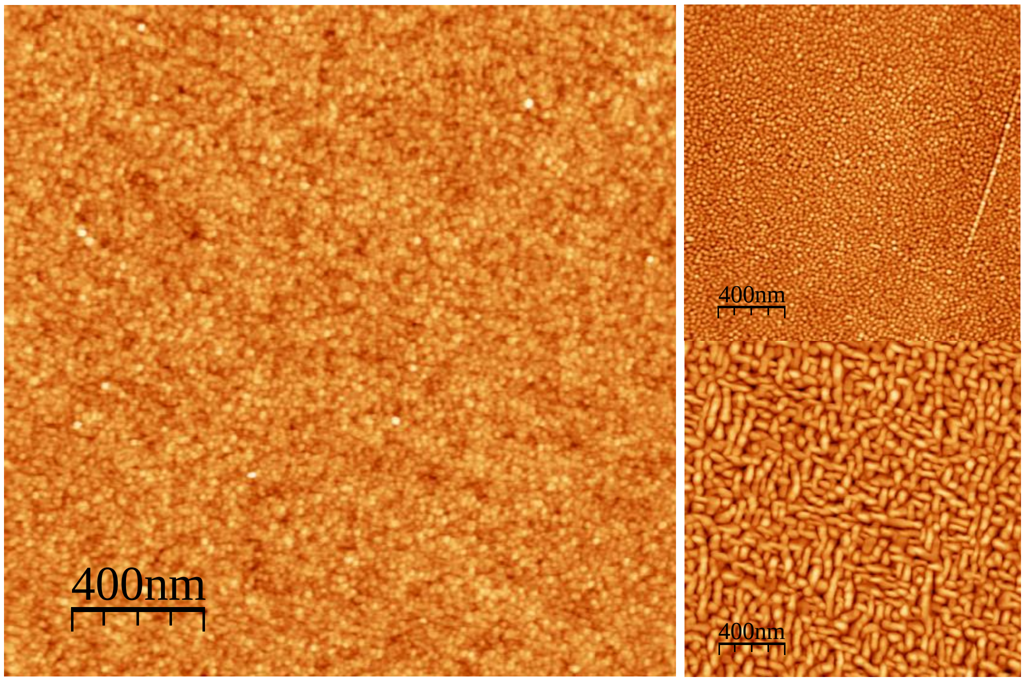


All NbN films are ~200 nm thick based on XRR/Profilometry

Compare Surface Morphology of Nb and NbN similar films

NbN

Nb(100)



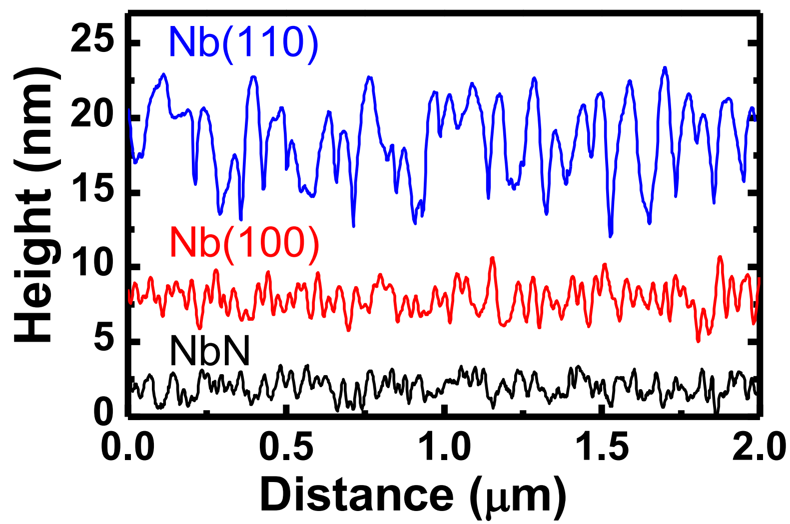
Nb(110)

RMS Roughness for comparable film thickness:

NbN <1 nm

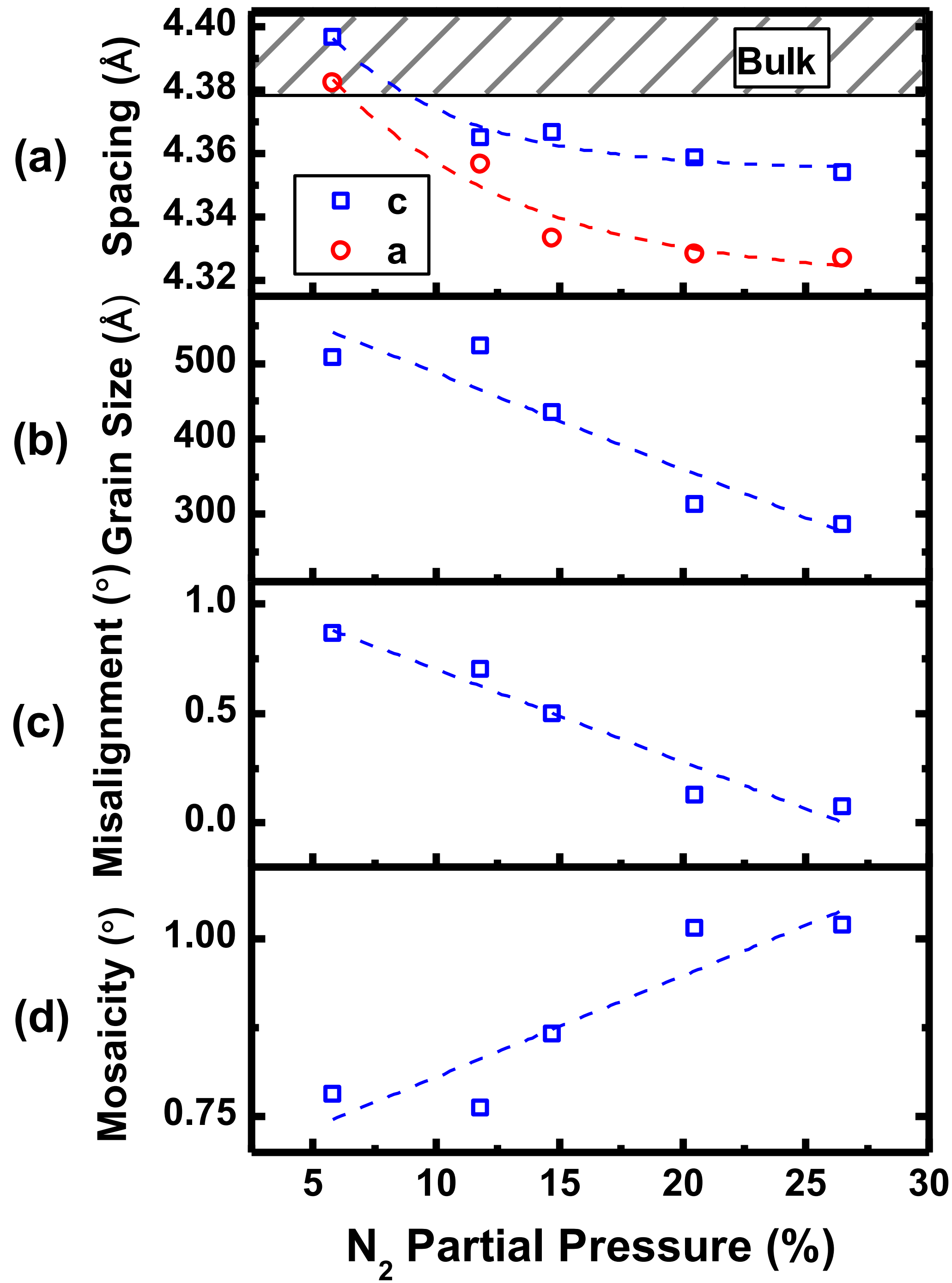
Nb(100) 1.21 nm

Nb(110) 2.45 nm

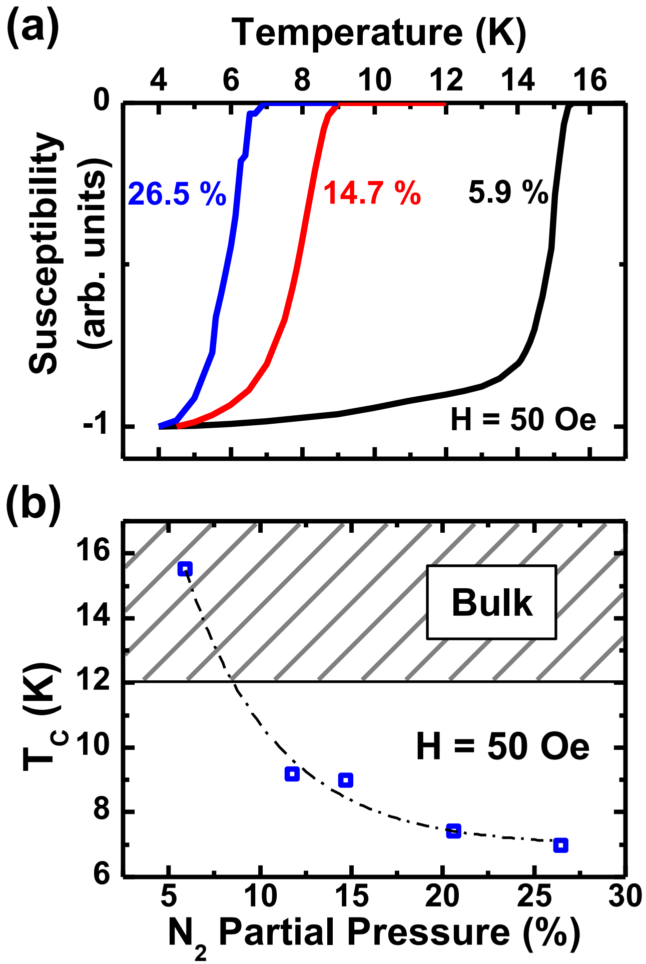


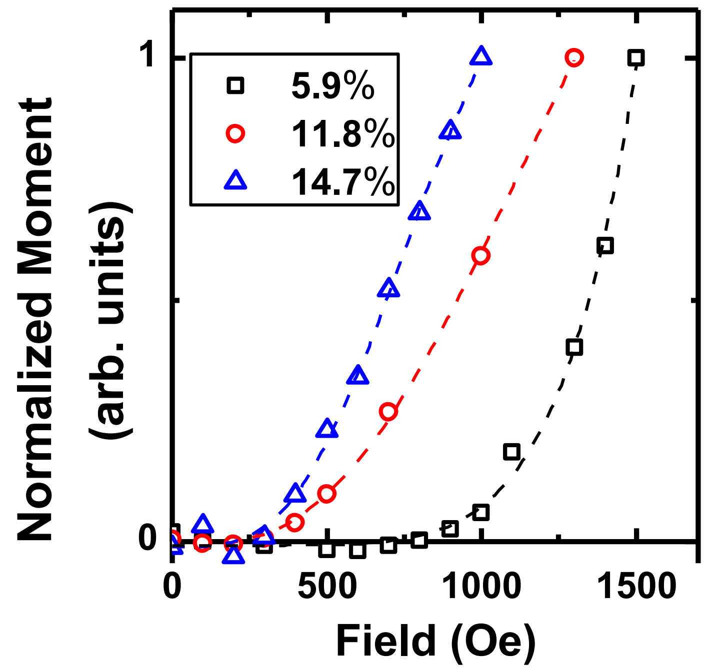
D. B. Beringer, W. M. Roach, C. Clavero, C. E. Reece and **R. A. Lukaszew**, "Roughness analysis applied to niobium thin films grown on MgO(001) surfaces for superconducting radio frequency cavity applications" accepted for publication in *Phys. Rev. ST Accel. Beams* (2012).

NbN films microstructure



Superconducting Properties



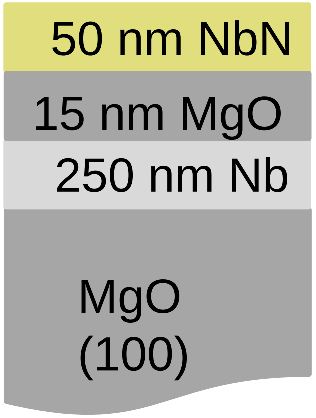


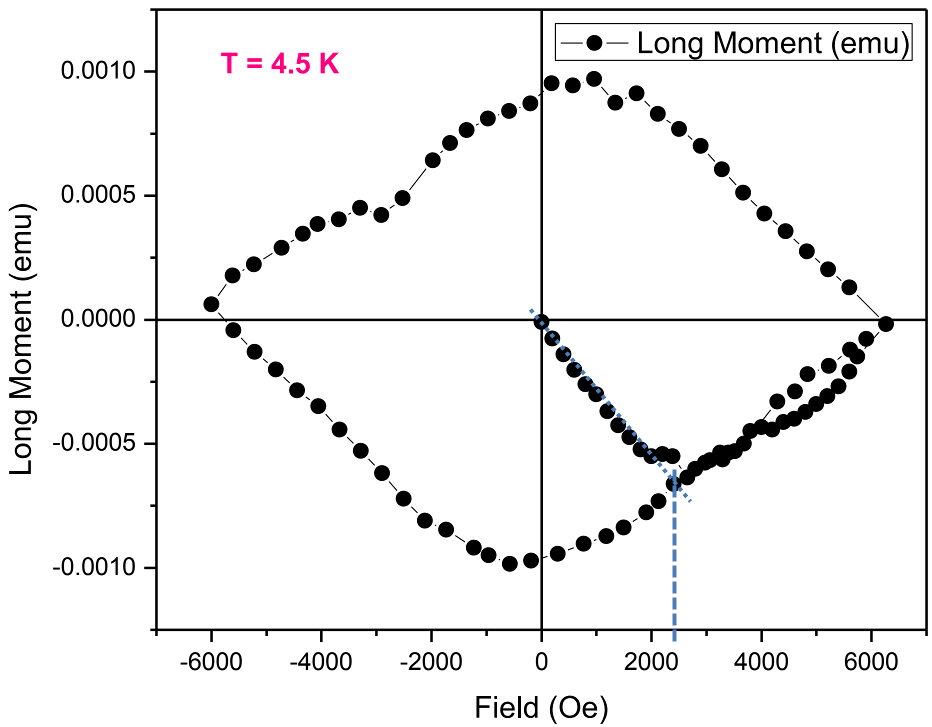
W. M. Roach, J. R. Skuza, D. B. Beringer, Z. Li, C. Clavero, and **R. A. Lukaszew**, “NbN thin films for superconducting radio frequency cavities”. *Supercond. Sci.Technol*. **25**, 125016 (2012).

SIS trilayers

- NbN-based, MgB_2 based and NbTiN-based trilayers

NbN-based multilayer





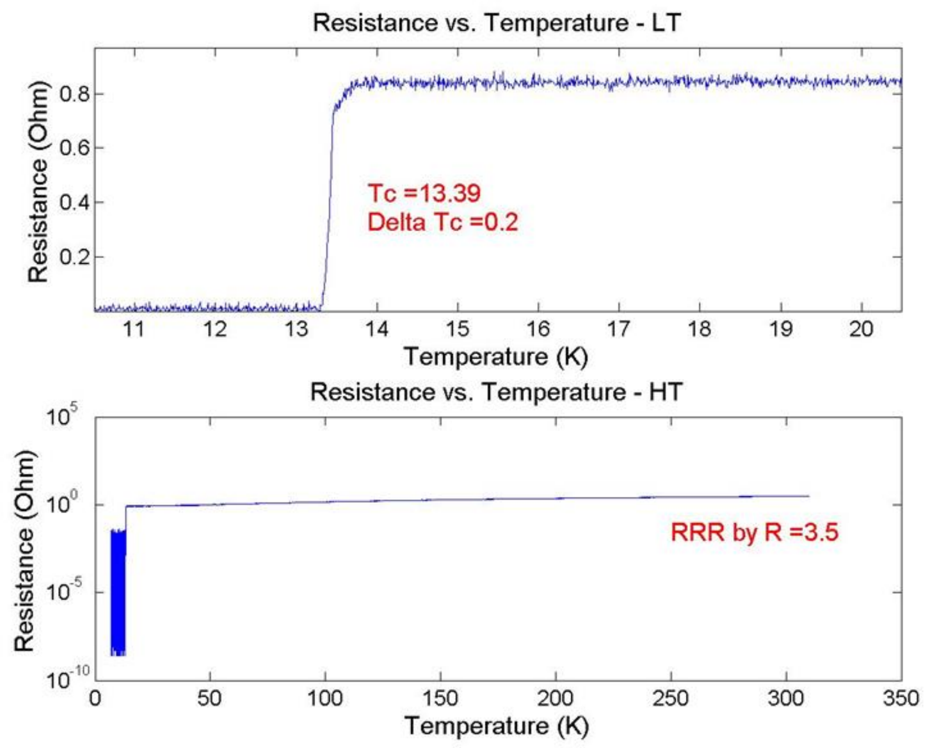
$H_{c1\text{-NbN-based-Multilayer}}$ ~ 220 mT!

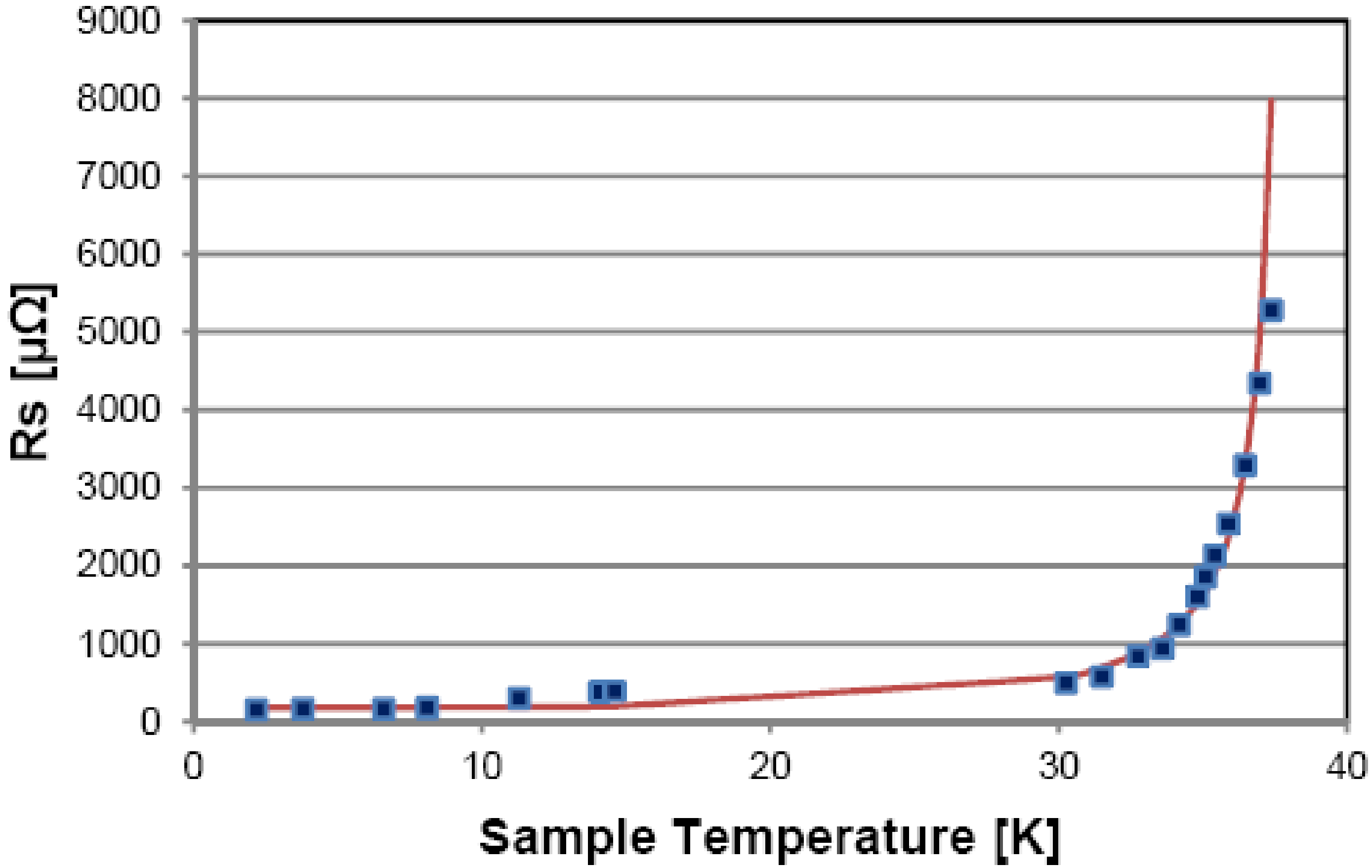
$H_{c1\text{-bulk Nb}}$ = 170 mT

"Magnetic Shielding Larger than the Lower Critical Field of Niobium in Multilayers" W. M. Roach, D. B. Beringer, Z. Li, C. Clavero, and R. A. Lukaszew, *IEEE Trans. Appl. Supercond.* **23**, 8600203 (2013).

Recent data on NbN-based multilayers

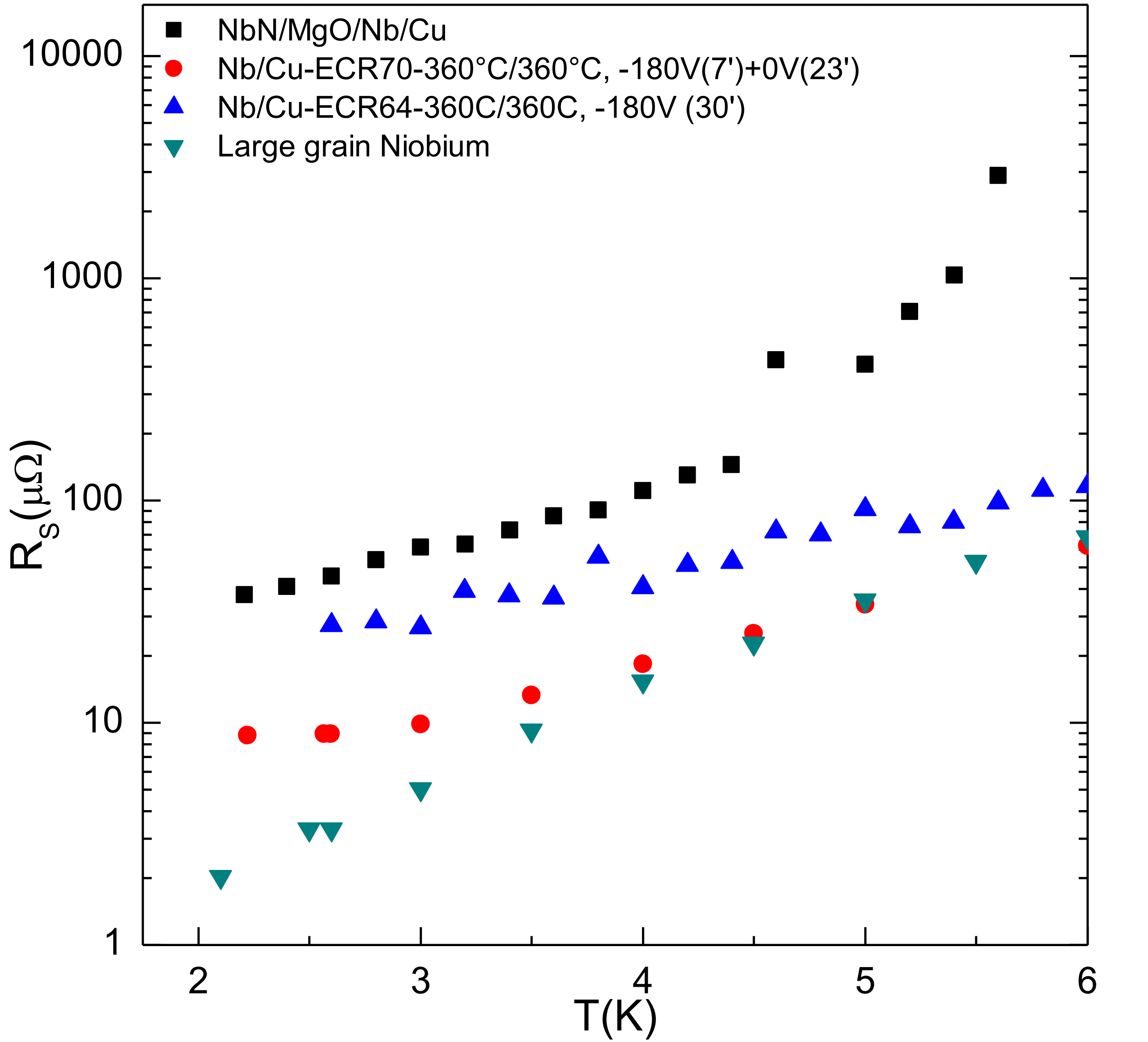
- Our most recent RRR data indicates that we have been able to improve the overall quality of our individual NbN layers since we obtain a Tc ~ 13.5K and RRR ~ 4.7 comparable to the values obtained when the NbN films were grown on (001) MgO substrates.





At the SRF 2011 the surface impedance of a MgB_2-based multilayer was reported, and the residual resistance was found ~ 181 μΩ

We notice that the residual resistance of these thin film samples is one order larger than that of bulk Nb around 2K but in general lower than that of MgB_2-based ML samples.



Science & Technology Facilities Council

Development of thin films for superconducting RF cavities in ASTeC

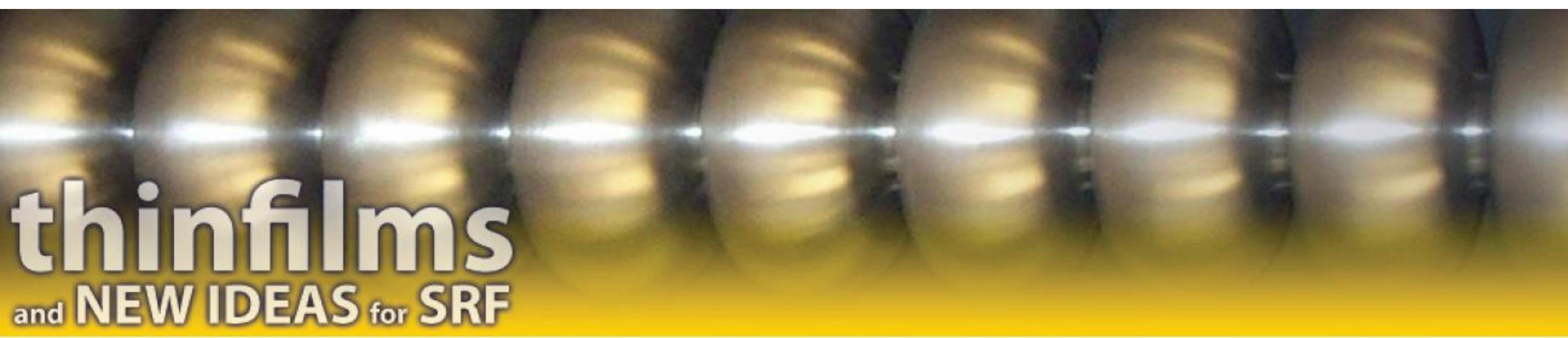
O.B. Malyshev and R. Valizadeh

on behalf of collaboration team

ASTeC

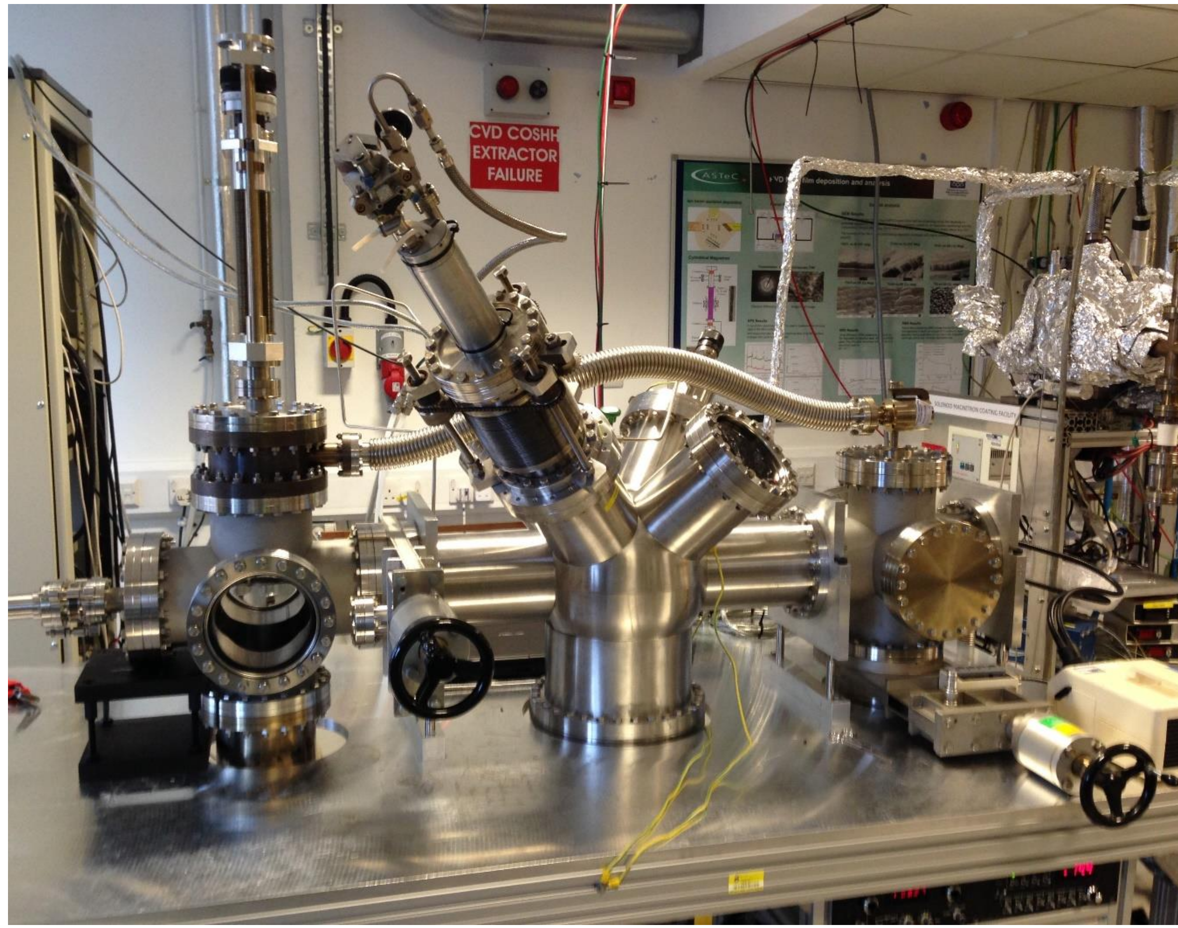
ASTeC Vacuum Science Group,

STFC Daresbury Laboratory, UK



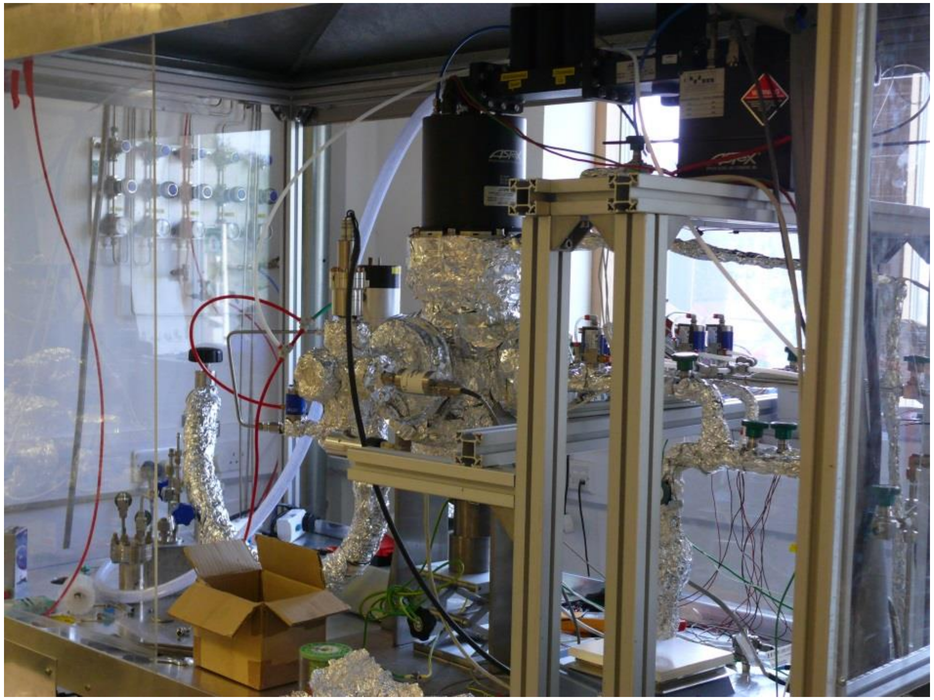
UHV PVD facility

- Bakeable
- Load-lock chamber
- ≤100 mm diam.
- Three planar concentric targets with the variable distance to the substrate: 10-15 cm
- Substrate rotation
- Ion beam assist
- $20 \leq T_s \leq 950$ ºC
- Differential RGA pumping to analyse the sputter gas.



PECVD/ALD deposition

- Base pressure:
  - 1.5 x 10^{-5} mbar at 120 ºC
- Gas flows:
  - Argon, Max 5 l/min, 200 sccm MFC
  - Hydrogen, Max 1 l/min, 100 sccm MFC
- Heater tested up to 500 ºC (could go 950 ºC)

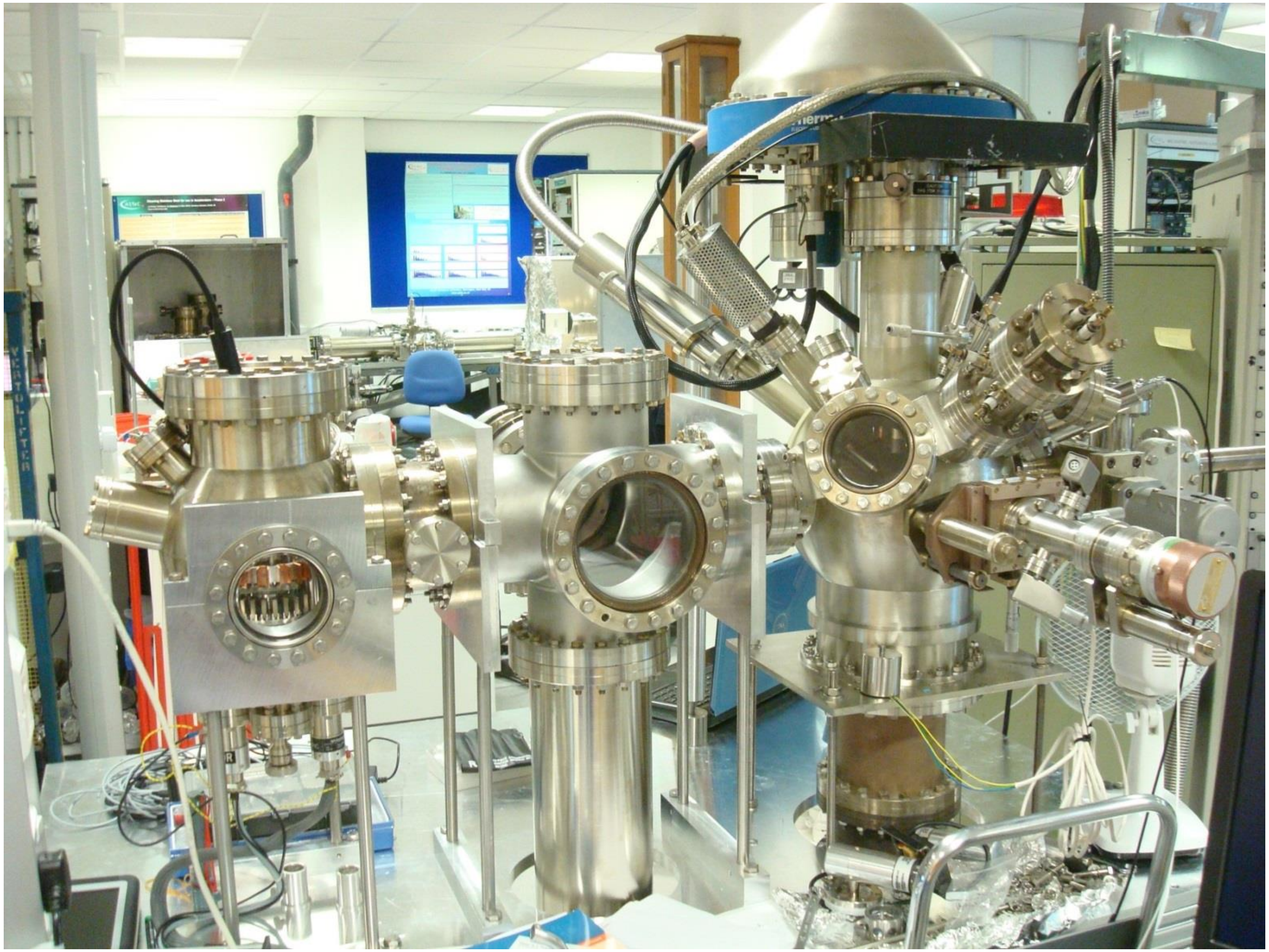


- First Nb film using $NbCl_5$ precursor was deposited on last Friday

Film Morphology

- **XRD** analysis
  - average grain size and lattice orientations within the film.
- **XPS** analysis
  - film composition and impurity
- **EBSD** analysis
  - an accurate value for the grain size at the surface of the film.
- **SEM** analysis
  - to determine the film thickness and growth rates.
  - to give an indication of the type of film that has been deposited i.e., columnar with voids or densely packed grains.

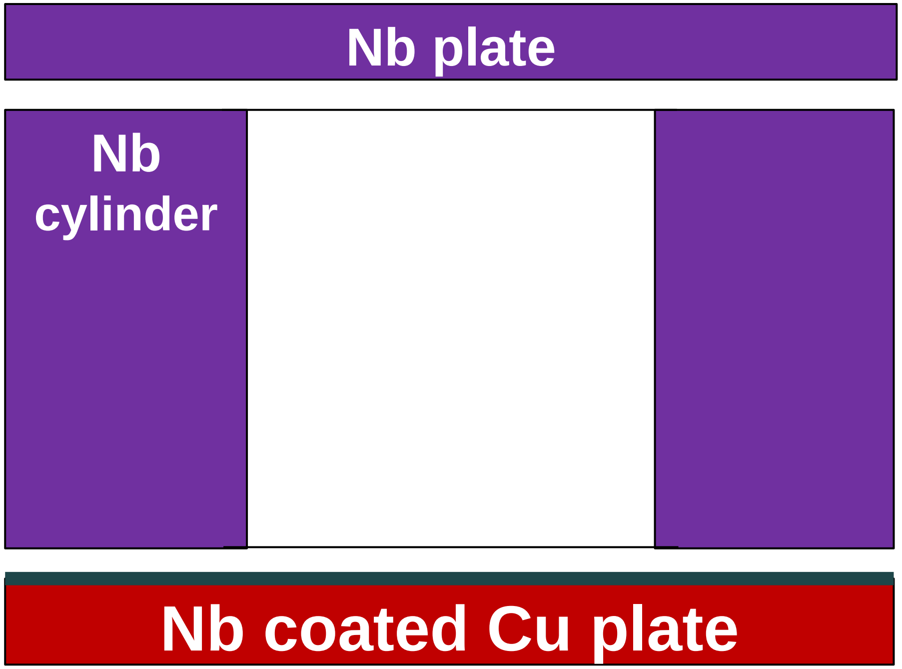
Multi-Probe UHV XPS, AES, AFM, STM, LEED and ISS



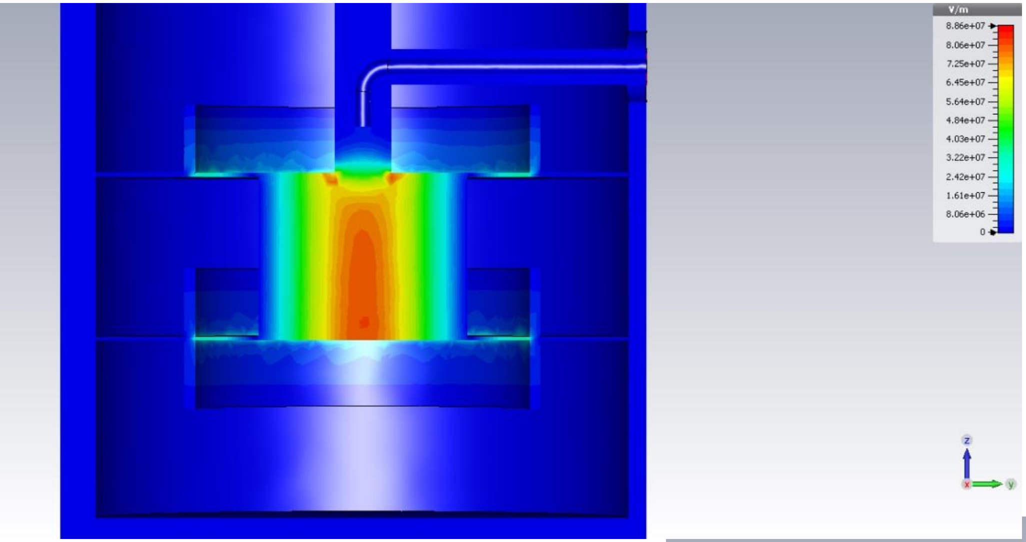
RF sample test: idea

We would like to make a simple RF evaluation of deposited film

- Tangential magnetic field
- Surface resistance (power loss) measurements at each part
- Nb coated sample comparison to bulk Nb and other samples

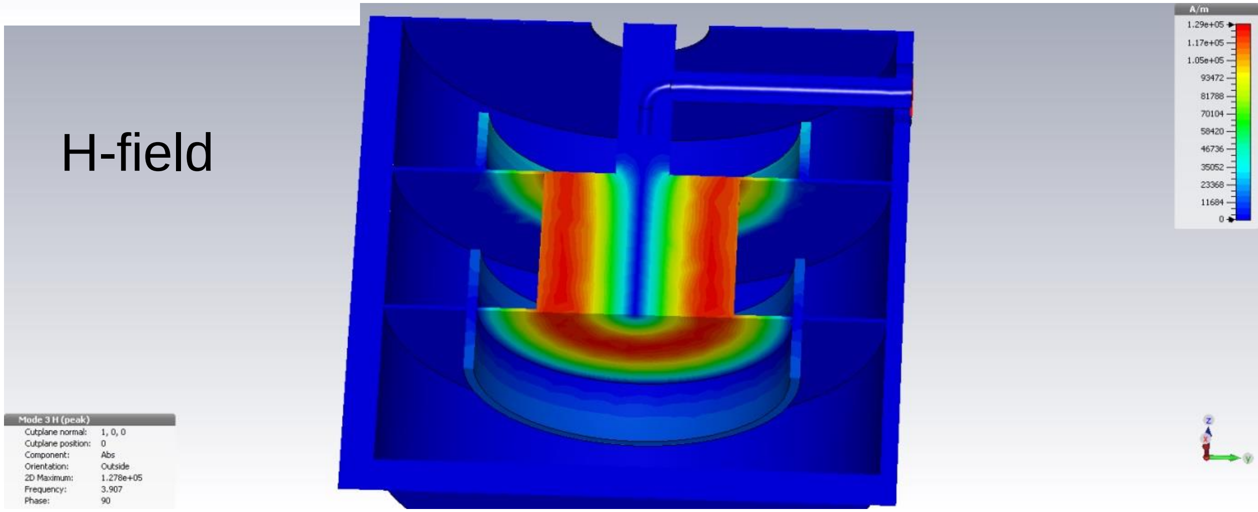


RF modelling for 3.9 GHz

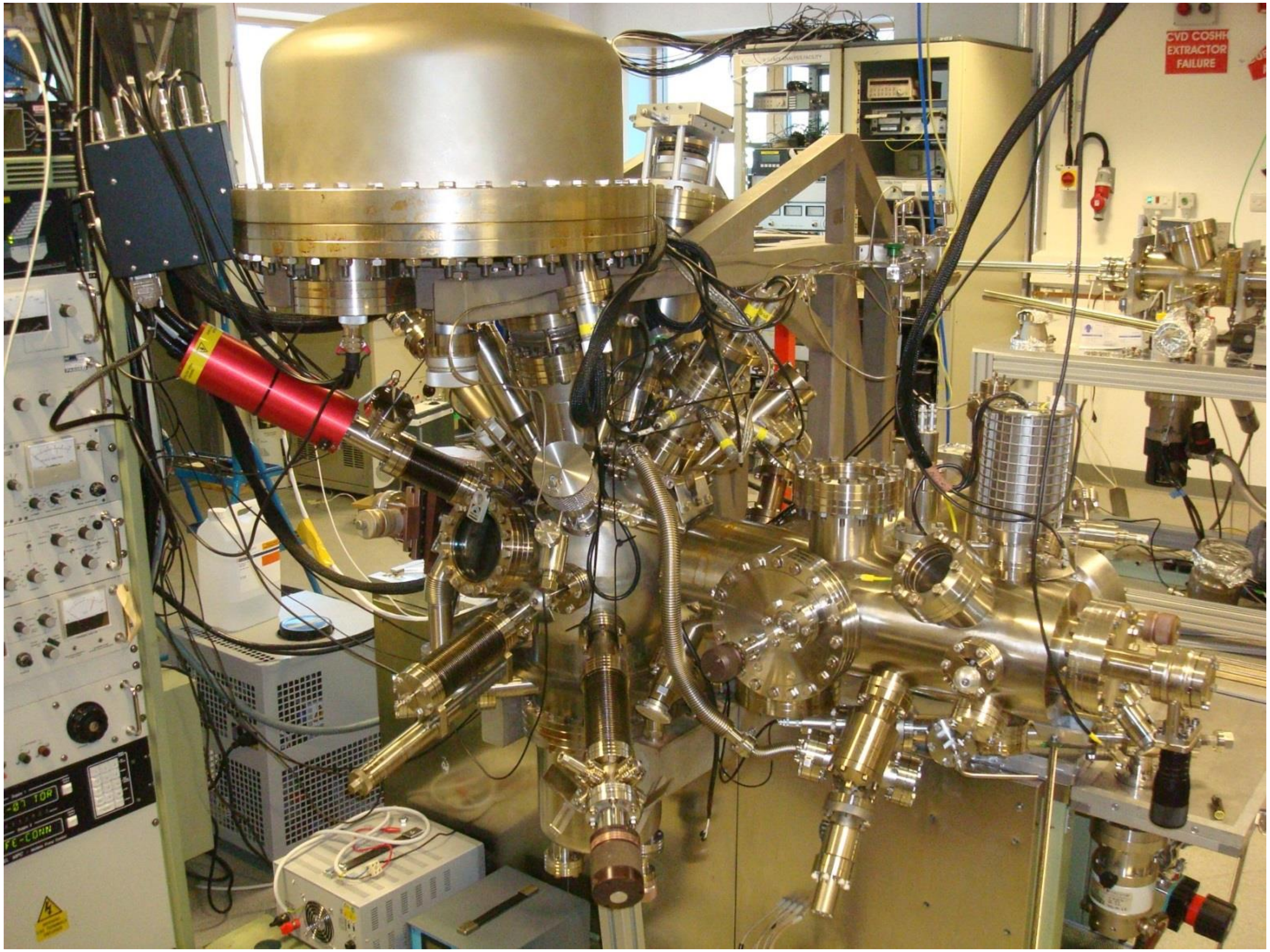


- The idea was found to be working
- There is an RF leakage in the gaps

- Optimisation work on bandwidth and behaviour at very high conductivity with Microwave Studio



ESCAlab-II: monochromated XPS, mapping Auger, UPS



Surface Resistance of a bulk-like Nb Film

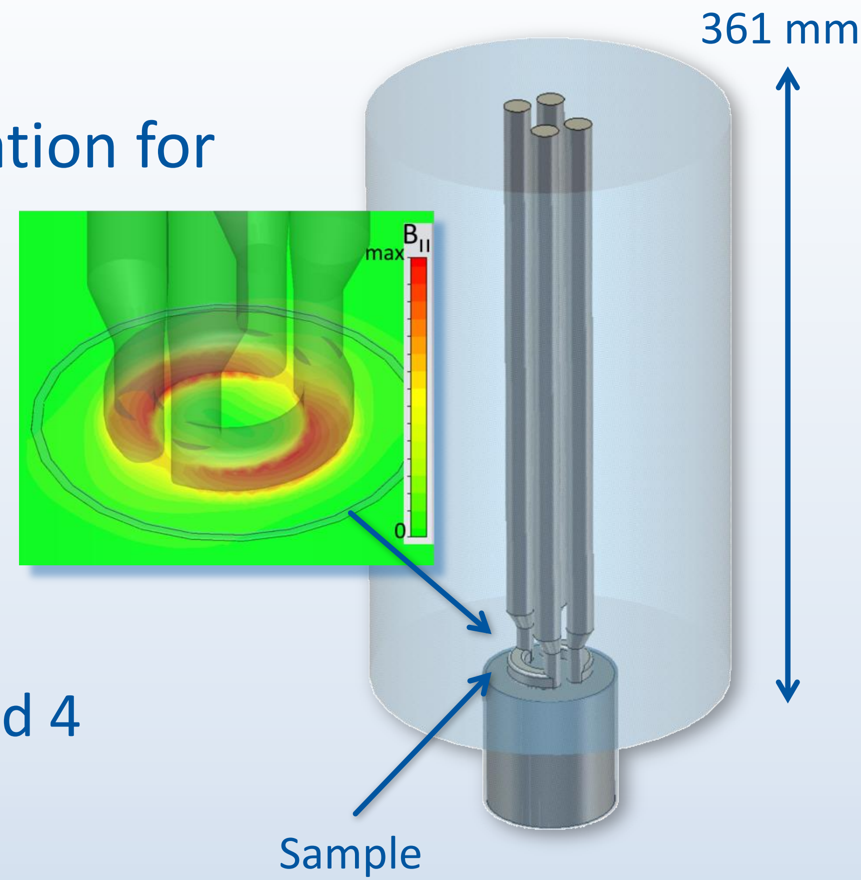
Sarah Aull, Anne-Marie Valente-Feliciano, Tobias Junginger and Jens Knobloch

UNIVERSITÄT SIEGEN
CERN

The Quadrupole Resonator

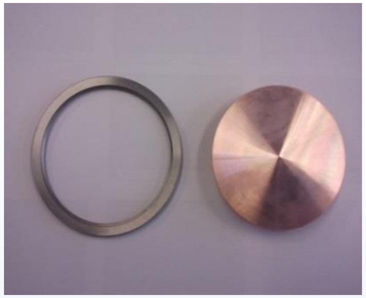
- Resonant frequencies:

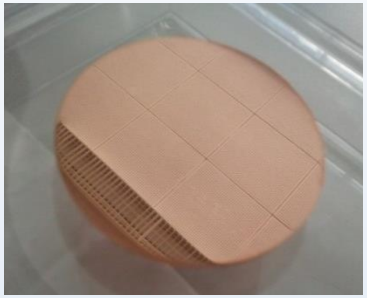
  400, 800, 1200 MHz
- Same magnetic field configuration for all frequencies
- $B_{max} \approx 60$ mT
- Temperatures 1.8 -20 K
- Sample:
  - 75 mm diameter
  - Equipped with a dc heater and 4 temperature sensors

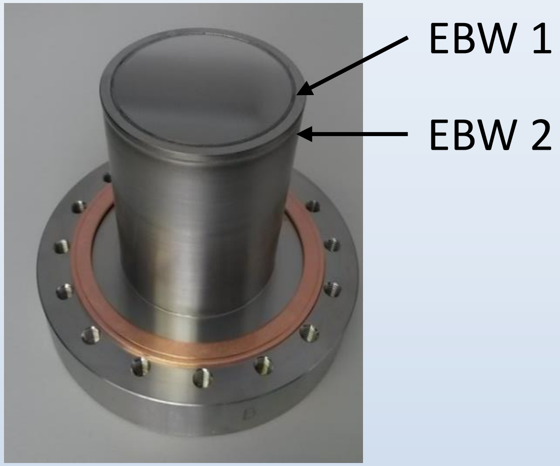


Sample Preparation

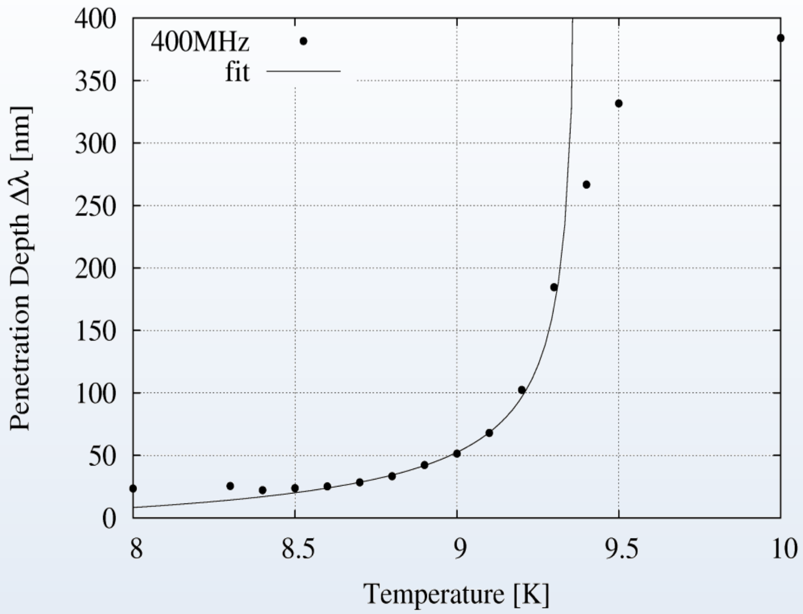
- OFHC copper substrate:
  - mechanically polished
  - Electron beam welded to Nb ring (EBW 1)
  - 12 µm electro polishing
  - Rinsing with ultra pure water at 6 bar
- Shipped to Jefferson Lab for coating
- Shipped back to CERN, EBW to support structure (EBW 2)
- Rinsing with ultra pure water at 6 bar
- Mounted in the quadrupole resonator







Penetration Depth Measurement



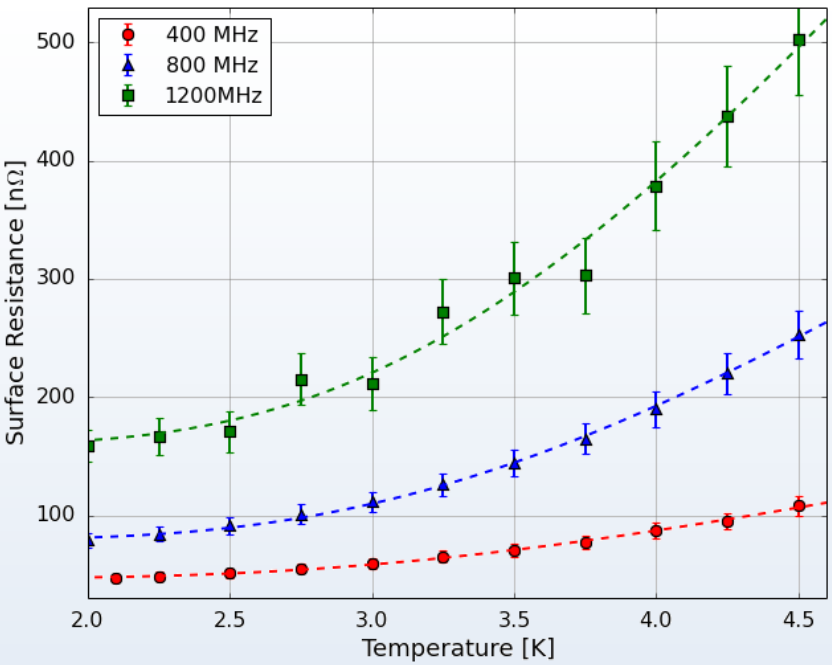
	λ(0K) [nm]
400 MHz	40 ± 2
800 MHz	38 ± 1
1200 MHz	38 ± 1

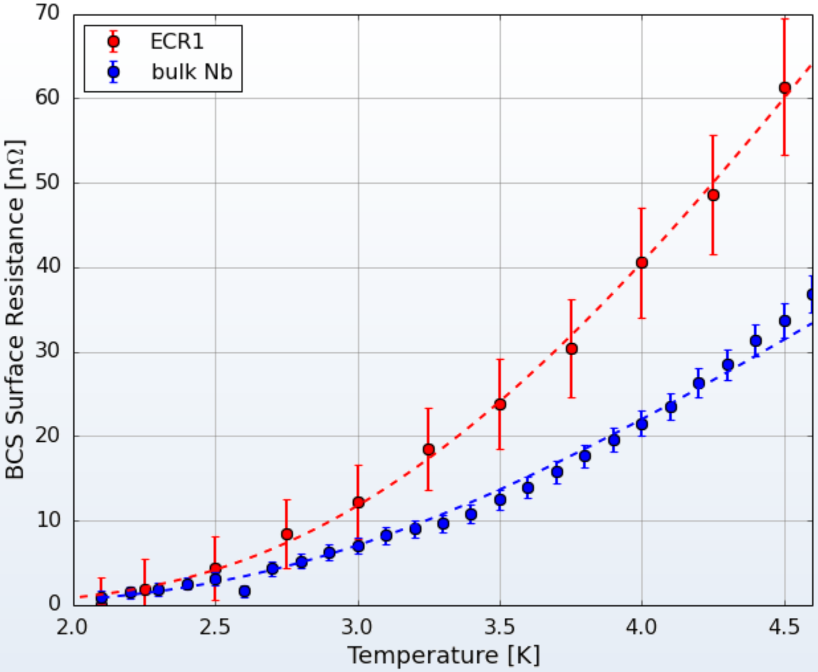
ℓ* [nm]	RRR
144 ± 20	53 ± 7

* with λ_L = 32 nm and ξ_0 = 39 nm

Bulk-like film in the clean limit

R(T): comparison with bulk Nb



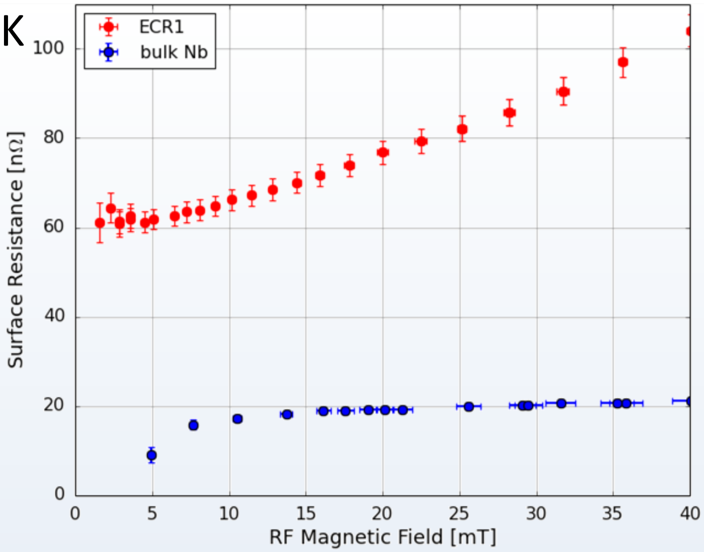


R(T) curve consistent with a film with RRR 50 and a reduced energy gap (might be due to strong oxidation)

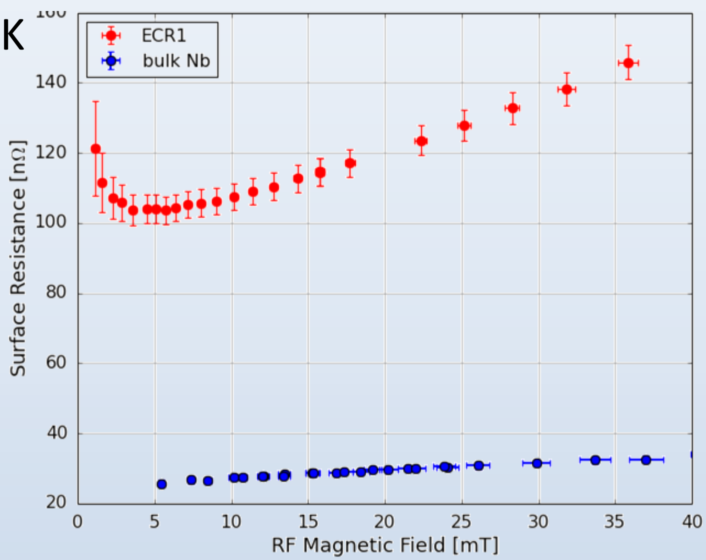
	R_{res} [nΩ]	Δ [K]
400 MHz	46.6 ± 0.8	14.2 ± 0.3
800 MHz	79 ± 2	14.8 ± 0.2
1200 MHz	156 ± 11	15.1 ± 1
mean		14.6 ± 0.2

Q-Slope: film vs. bulk

2.5 K



4 K

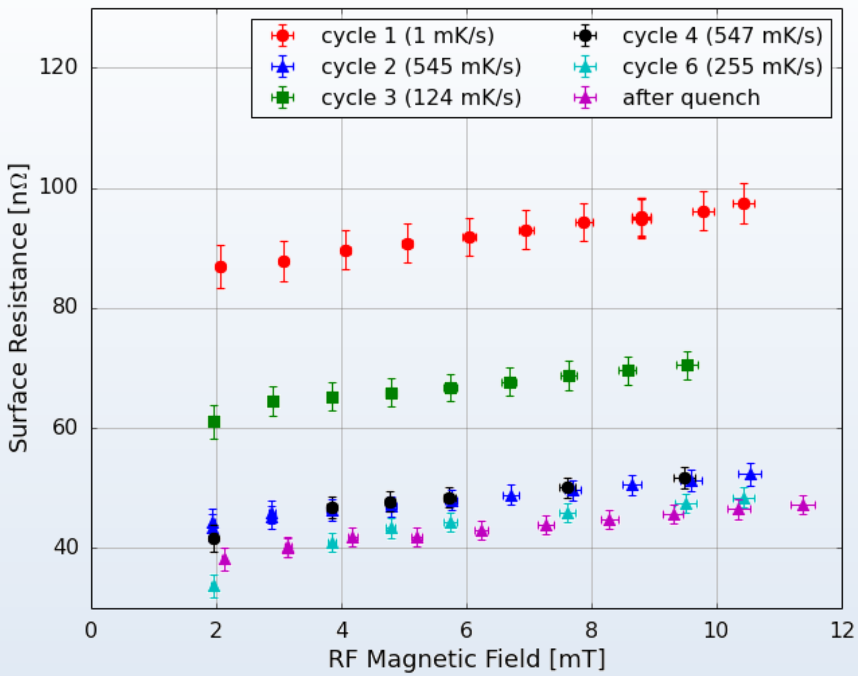


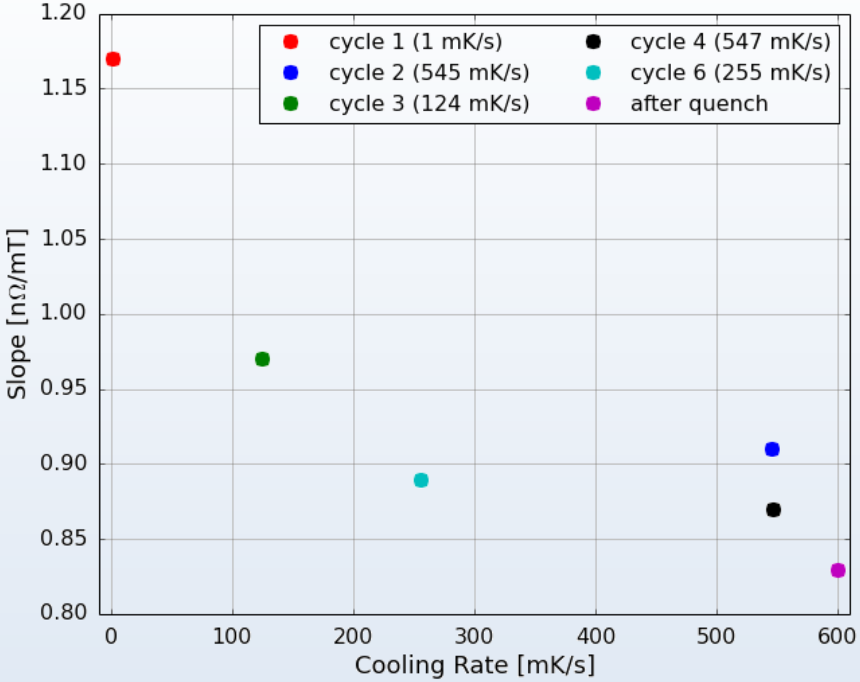
- Q-Slope of Nb film is linear for B > 5 mT for temperatures up to 4 K.
- Q-Slope of the Nb film is significantly stronger than for bulk Nb (1 order of magnitude)

RRR is unlikely the cause for the strong Q-slope of Nb films.

Influence of the Cooling Conditions

400 MHz, 2 K





Thermal cycling acts on the Q-slope:

The faster the cooling the flatter the slope.

Status of the HZB Quadrupole Resonator*

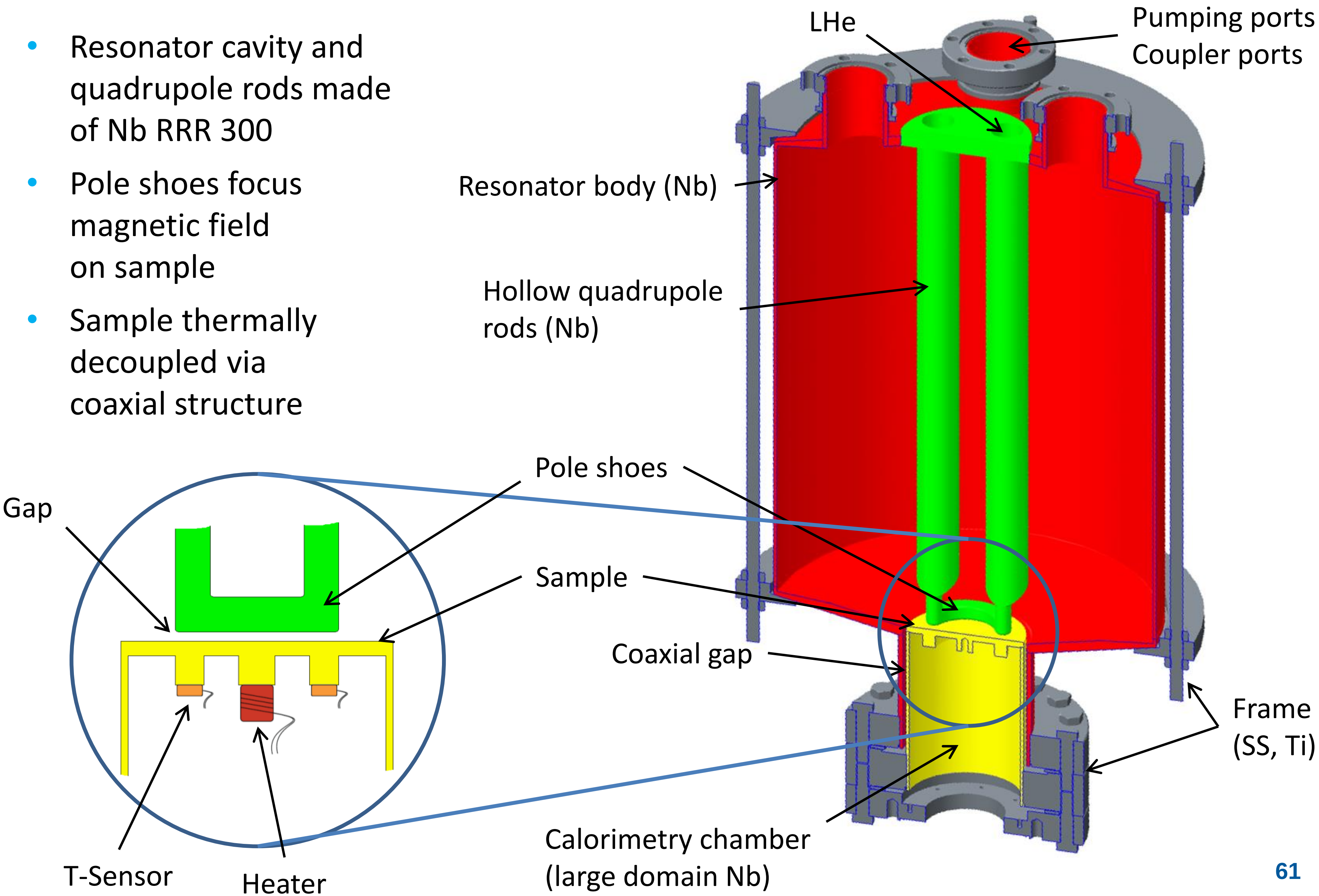
S. Keckert, R. Kleindienst, J. Knobloch, O. Kugeler

* work partly funded by EuCARD^2

The Quadrupole Resonator (QPR)

HZB Helmholtz Zentrum Berlin

- Resonator cavity and quadrupole rods made of Nb RRR 300
- Pole shoes focus magnetic field on sample
- Sample thermally decoupled via coaxial structure

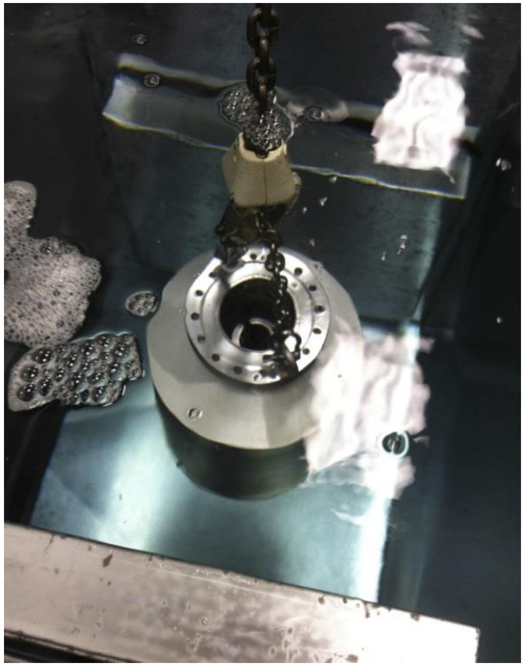


QPR preparation at JLab

HZB Helmholtz Zentrum Berlin

- QPR manufactured by Niowave
- Resonator shipped to JLab for surface treatment and first RF tests

BCP



Ultrasonic rinsing

600 °C bakeout for 12 hours

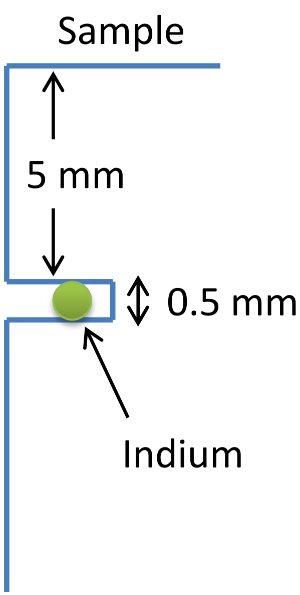
Pole shoes – view from below

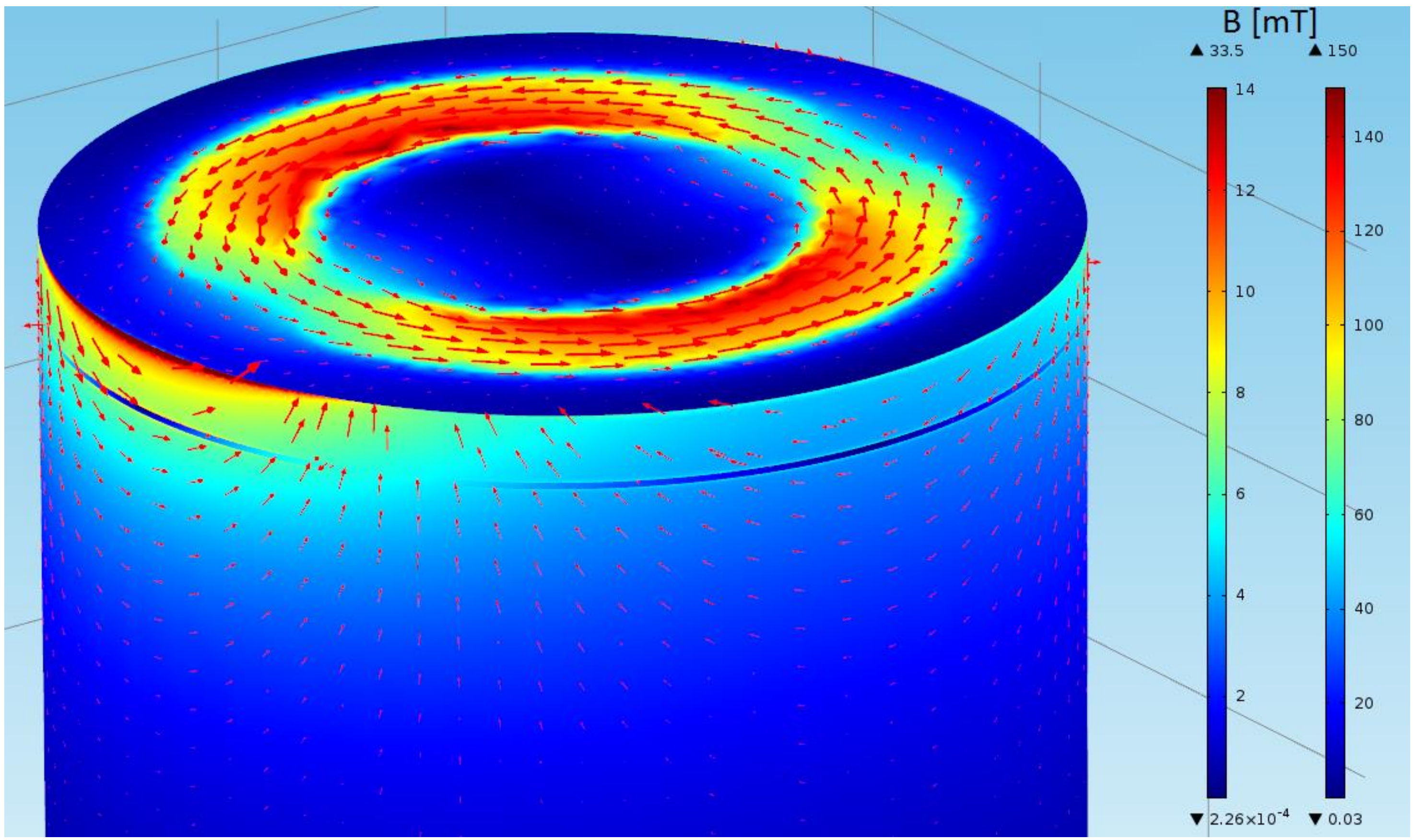
[Photos: A. Burrill, HZB]

RF simulations

- Impact of removable sample on RF?
  - Simulations using COMSOL 4.4
- Worst case: circumferential gap
  - Height: 0.5 mm
  - Position: 5 mm below sample
- Color plot:
  - Magnetic field [mT]
    (Different scales for sample and coax)
  - RF surface currents (red arrows)

→ Separated gaps of several millimeters are acceptable



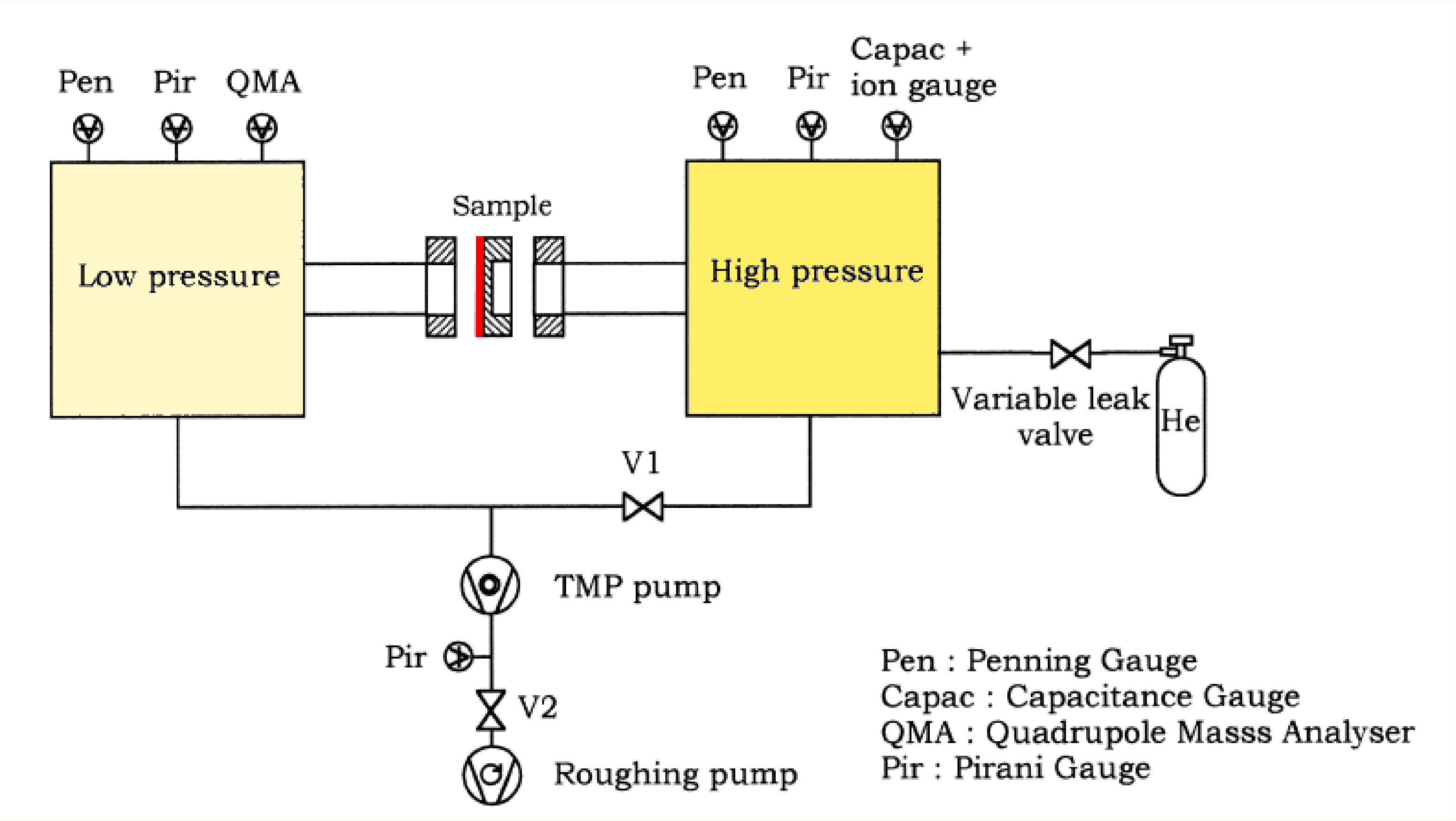


INFN
Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Legnaro

Porosity of Nb magnetron sputtered thin films and dependence on sputtering parameters

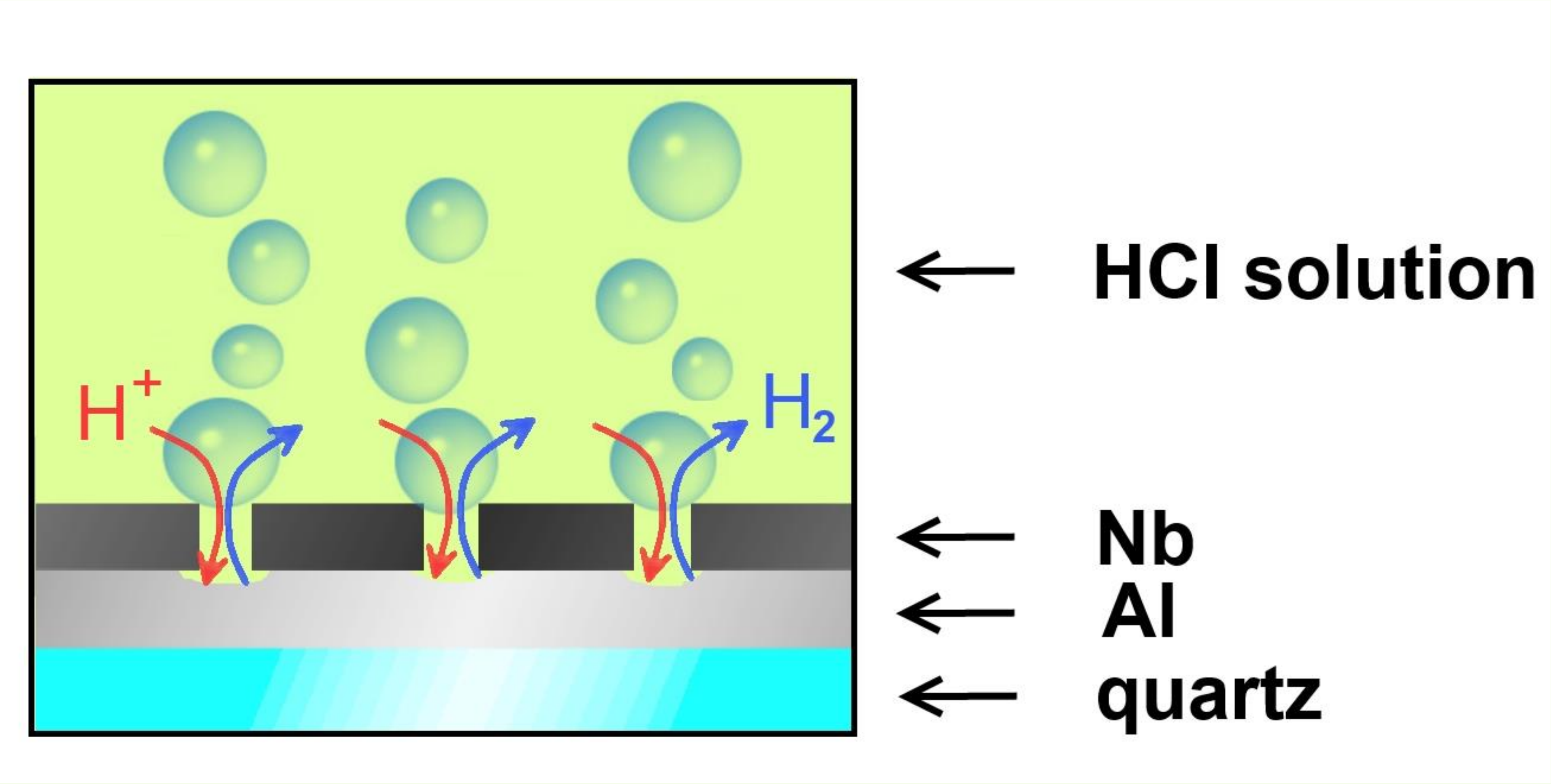
<u>Anna Skliarova</u>, O. Azzolini, V. Palmieri

Method proposed by Amorosi et al.

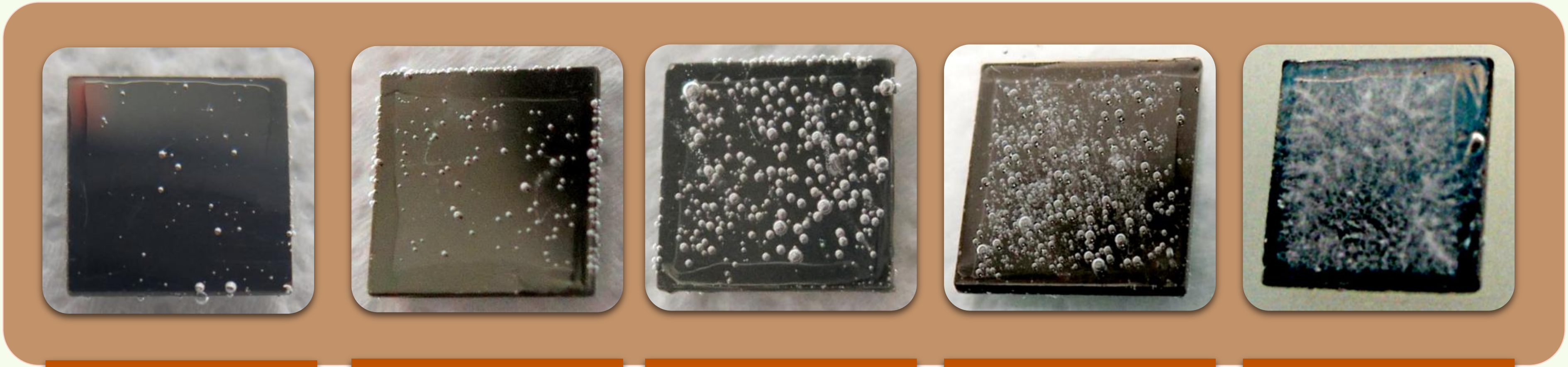


S. Amorosi, C. Benvenuti, P. Chiggiato, M. Malabaila,
Vacuum, V. 60, 1–2, 2001, 275-278

Our method of porosity evaluation



Acid test evaluation: SCALE

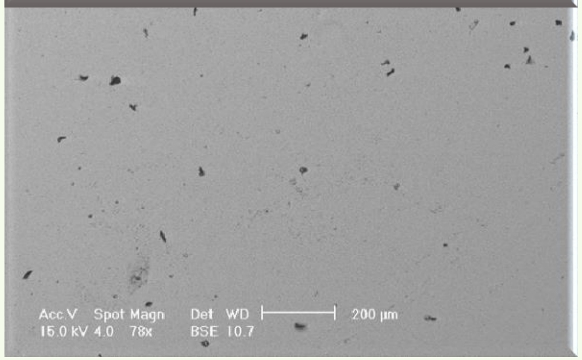


1	2	3	4	5

Temperature influence: SEM

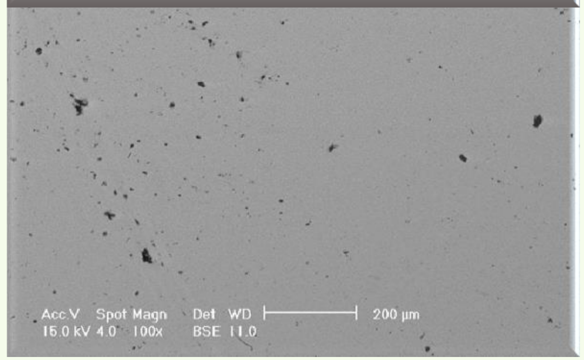
4 0.5 %

-100 °C



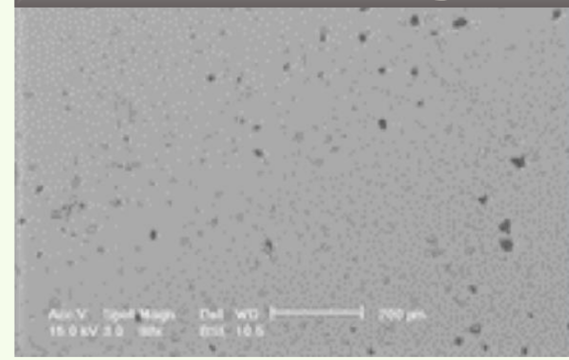
4 0.4 %

0 °C

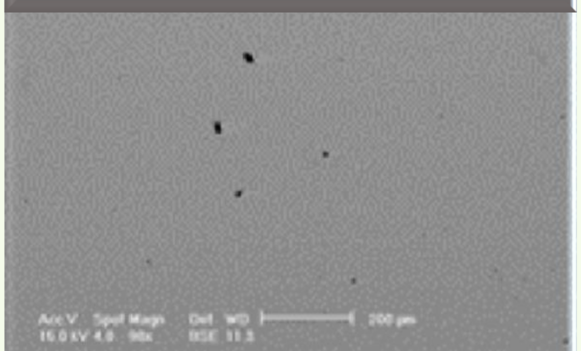


4 1 %

Floating

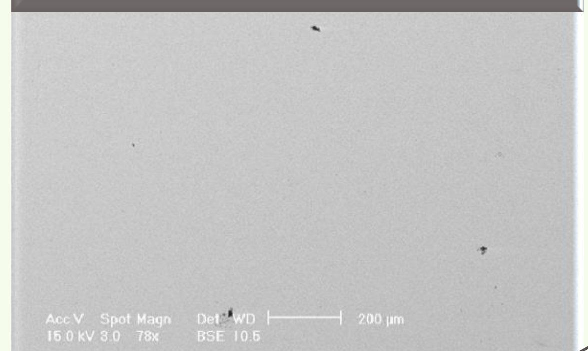


500 °C



3 0.04 %

800 °C



- 0 %

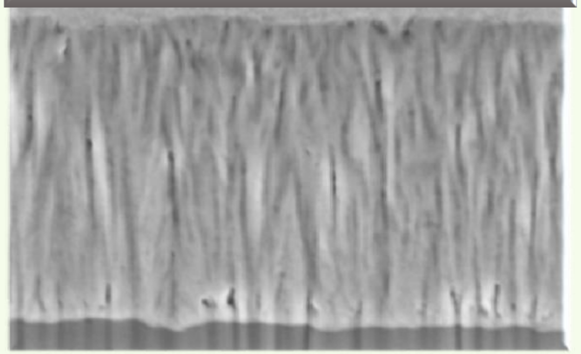
Acid test (1÷5)

Optical profilometry (%)

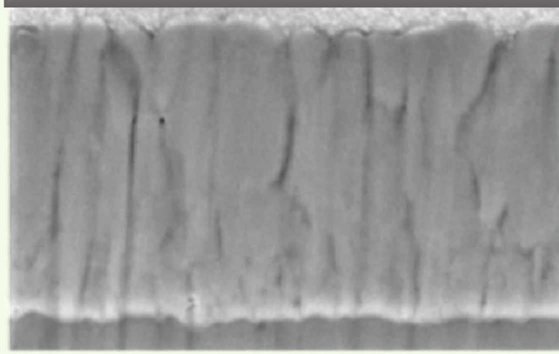
Temperature influence: FIB SEM

4 0.5 %	4 0.4 %	4 1 %

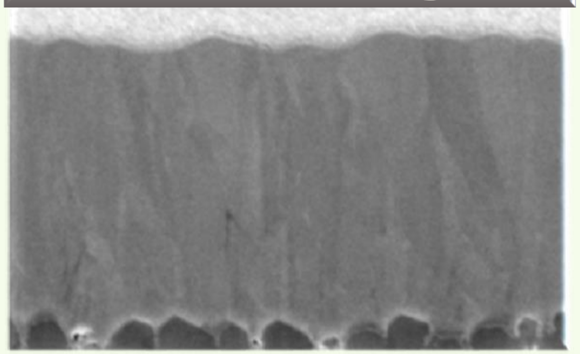
-100 °C



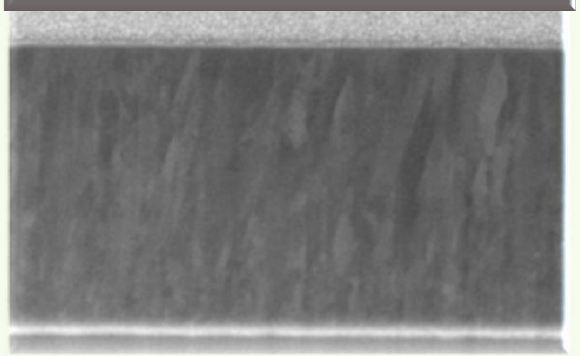
0 °C



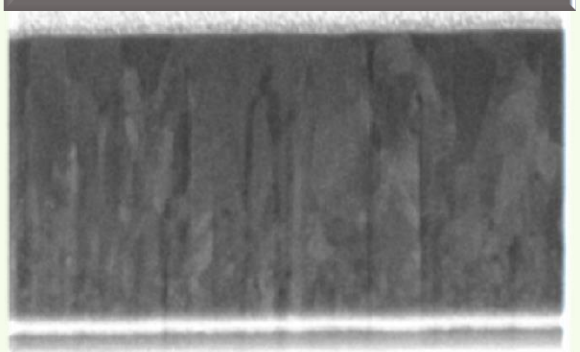
Floating



500 °C

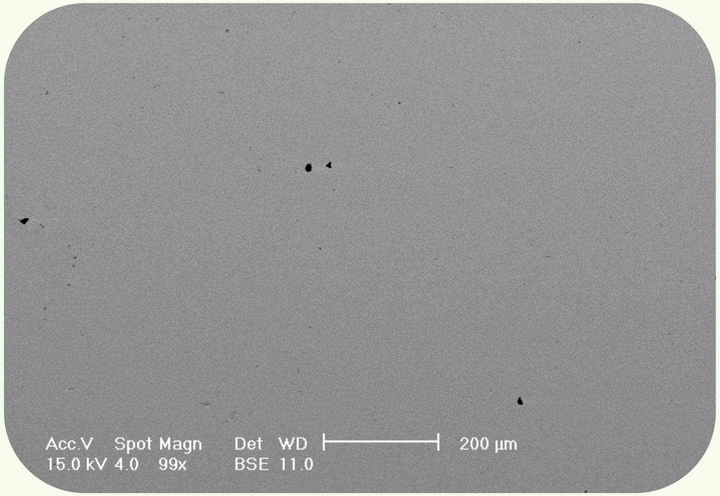


800 °C

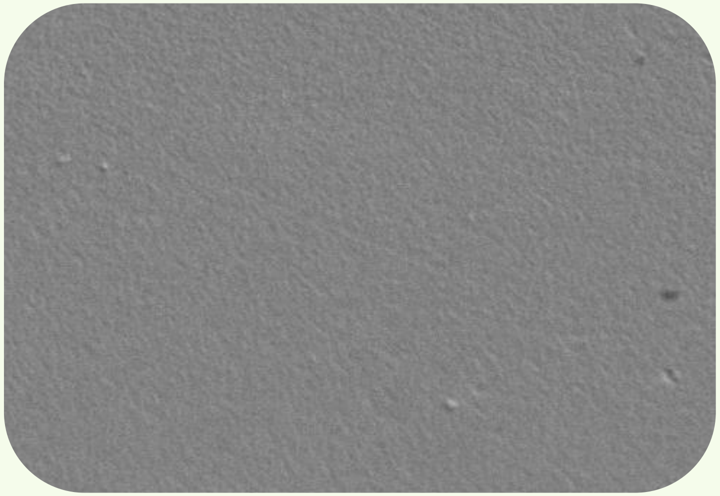


3 0.04 %	- 0 %

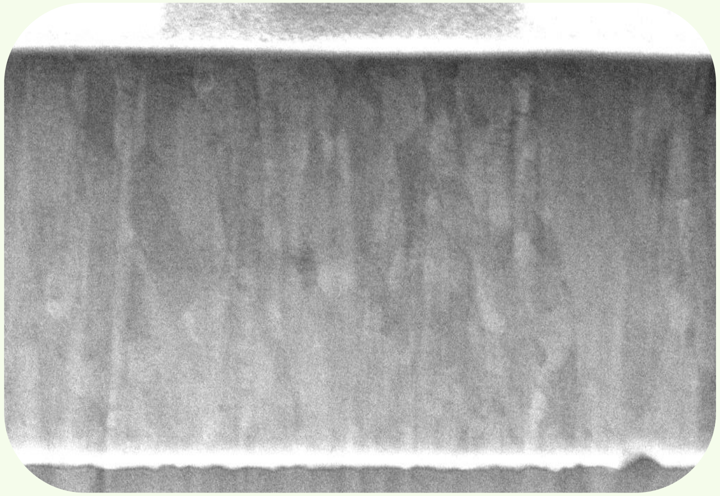
DC-biased MS



SEM



HR SEM



FIB SEM

Winners!

Nb-coated HIE-ISOLDE QWR SC Accelerating Cavities: coating process and film characterization

A. Sublet[1], N. Jecklin[1], S. Calatroni[1], G. Rosaz[1], W. Venturini Delsolaro[2], M. Therasse[2], P. Zhang[2], L. Dufay-Chanat [3], S. Prunet [3], B. Bártová[4], A.B. Aebersold[5], D. T. L. Alexander[5], M. Cantoni[5]

[1] CERN/TE/VSC

[2] CERN/BE/RF

[3] CERN/TE/CRG

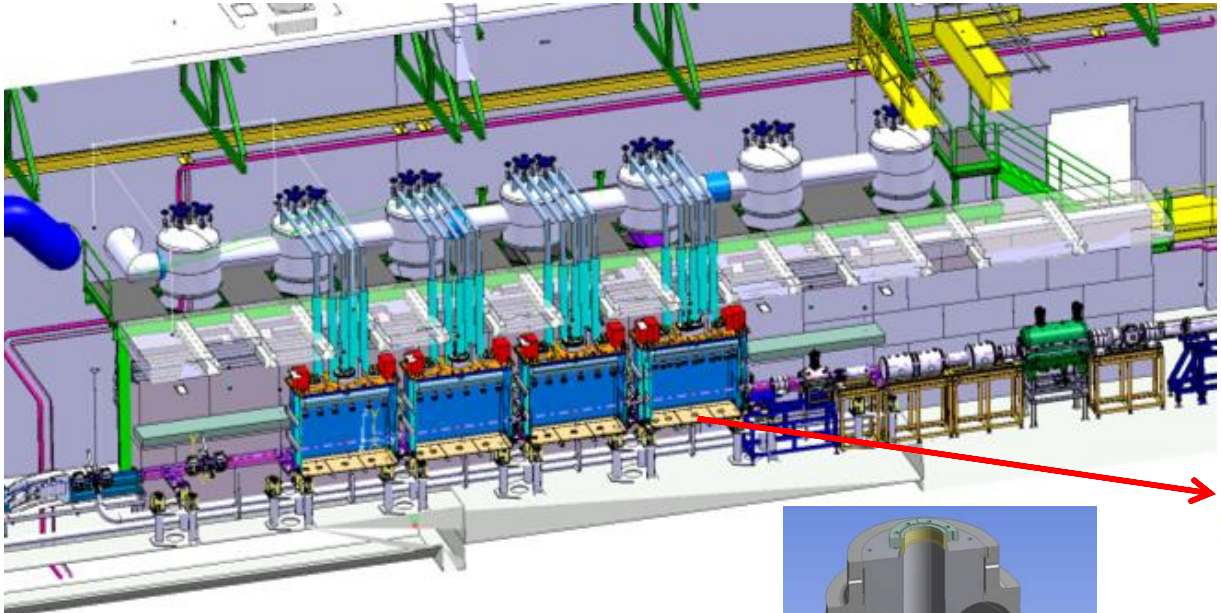
[4] CERN/EN/MME

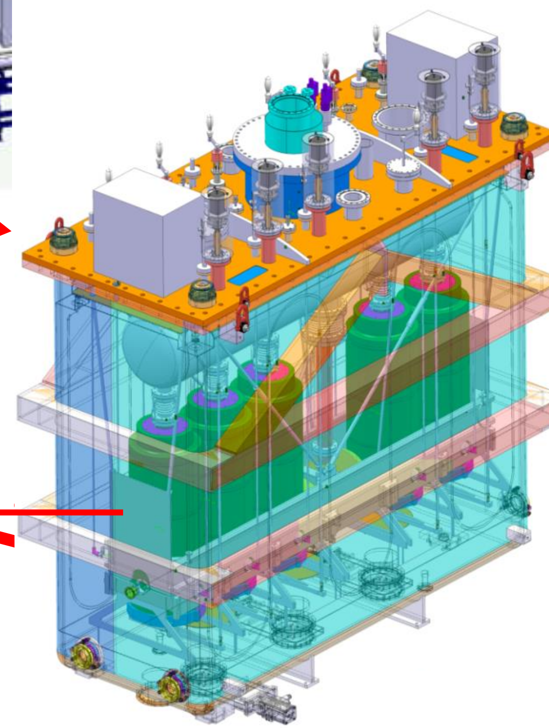
[5] EPFL, Interdisciplinary Centre for Electron Microscopy (CIME)

HIE-ISOLDE upgrade project

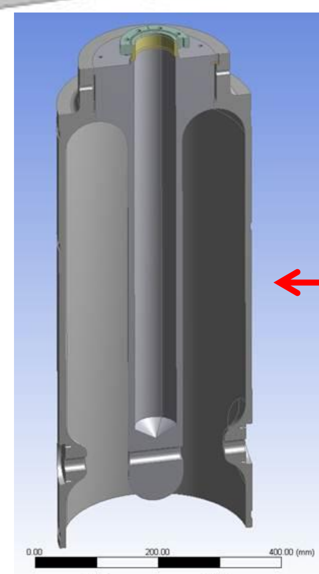
→ Boost the radioactive beam energy from 3MeV/u to 10MeV/u by using SC linac.

High Energy and Intensity – Isotope Separator On Line DEtector





Quarter-wave resonator (QWR):
Nb thin film sputtered
on 3D forged OFE Cu substrate



Production workflow

1 cavity per month

Cavity reception

Frequency tuning

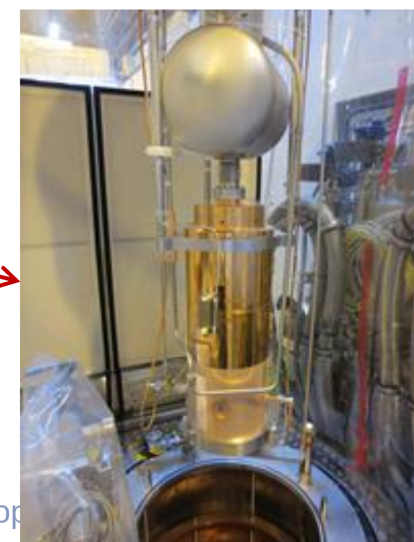
Surface treatment

Niobium coating

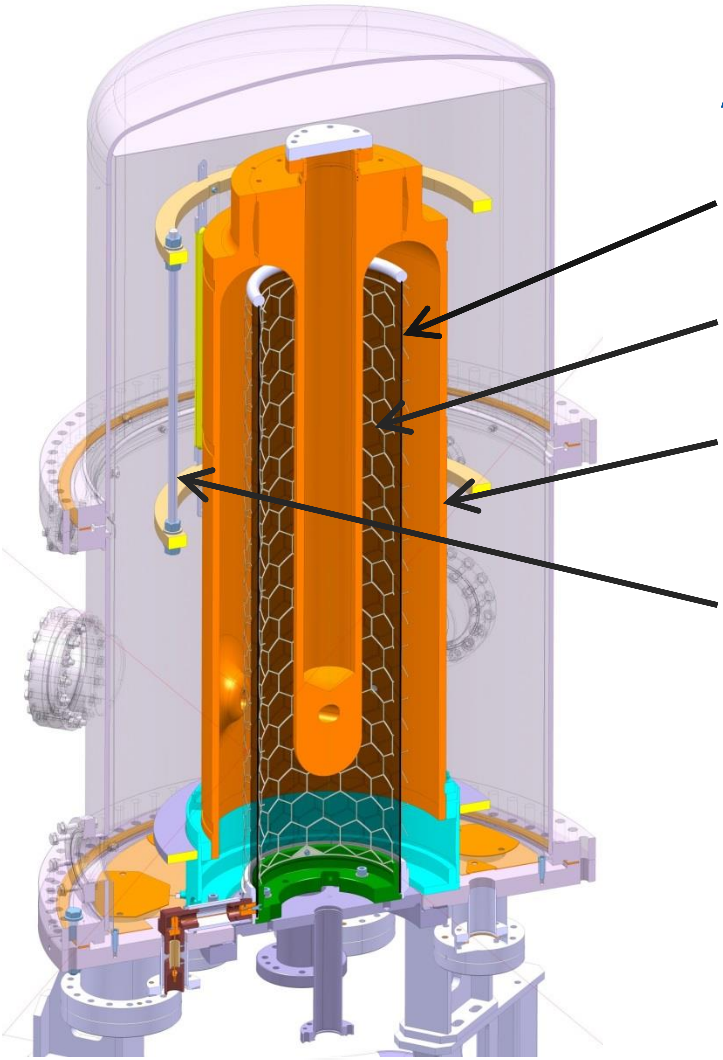
RF cold test

Cavity storage

Niobium Stripping n+1 cycle



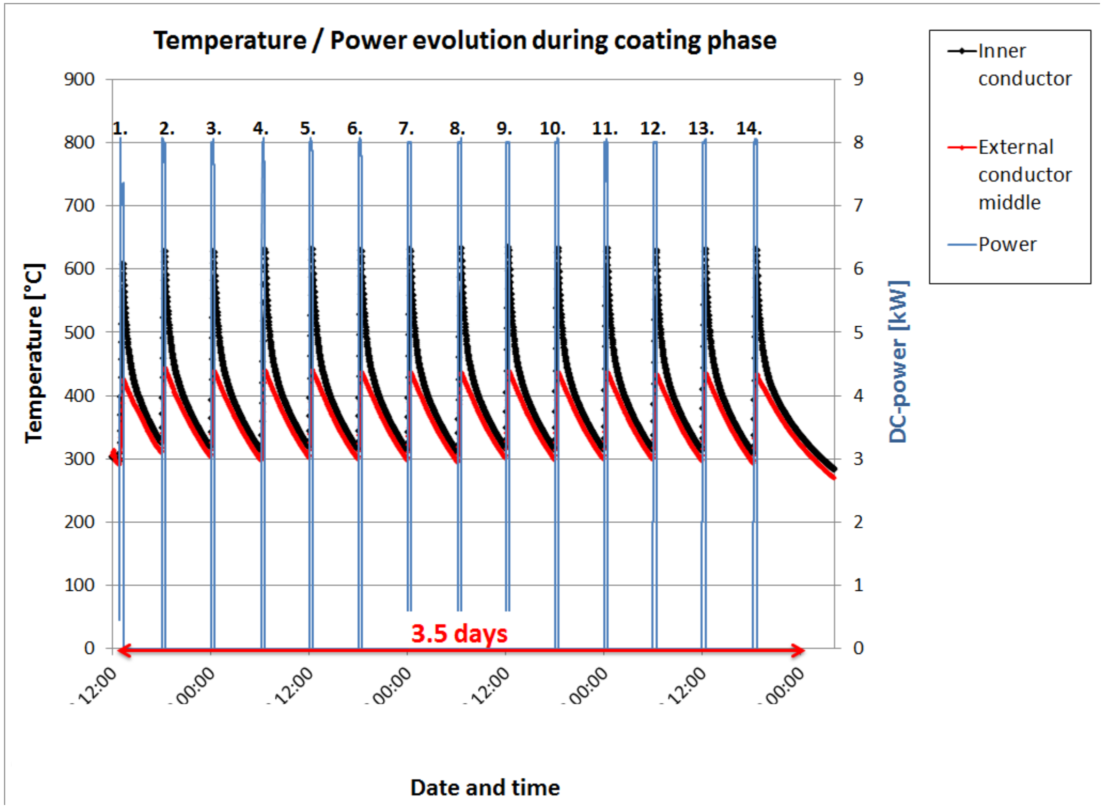
Coating hardware



2 coating benches functional at CERN:

- Nb cylindrical cathode at -1000V
- Grids grounded for plasma polarization
- Adjustable cavity bias:
  ions densify & smooth the Nb layer
- Cavity bakeout to 650°C with IR lamp prior to coating
- Coating with hot substrate (300-620°C)
- Thermocouples along cavity to monitor temperature during bakeout and coating
- Pressure control and RGA monitoring

Coating process



Baseline recipe DC-bias diode:

Pressure: 0.2mbar

Sputtering gas: Ar

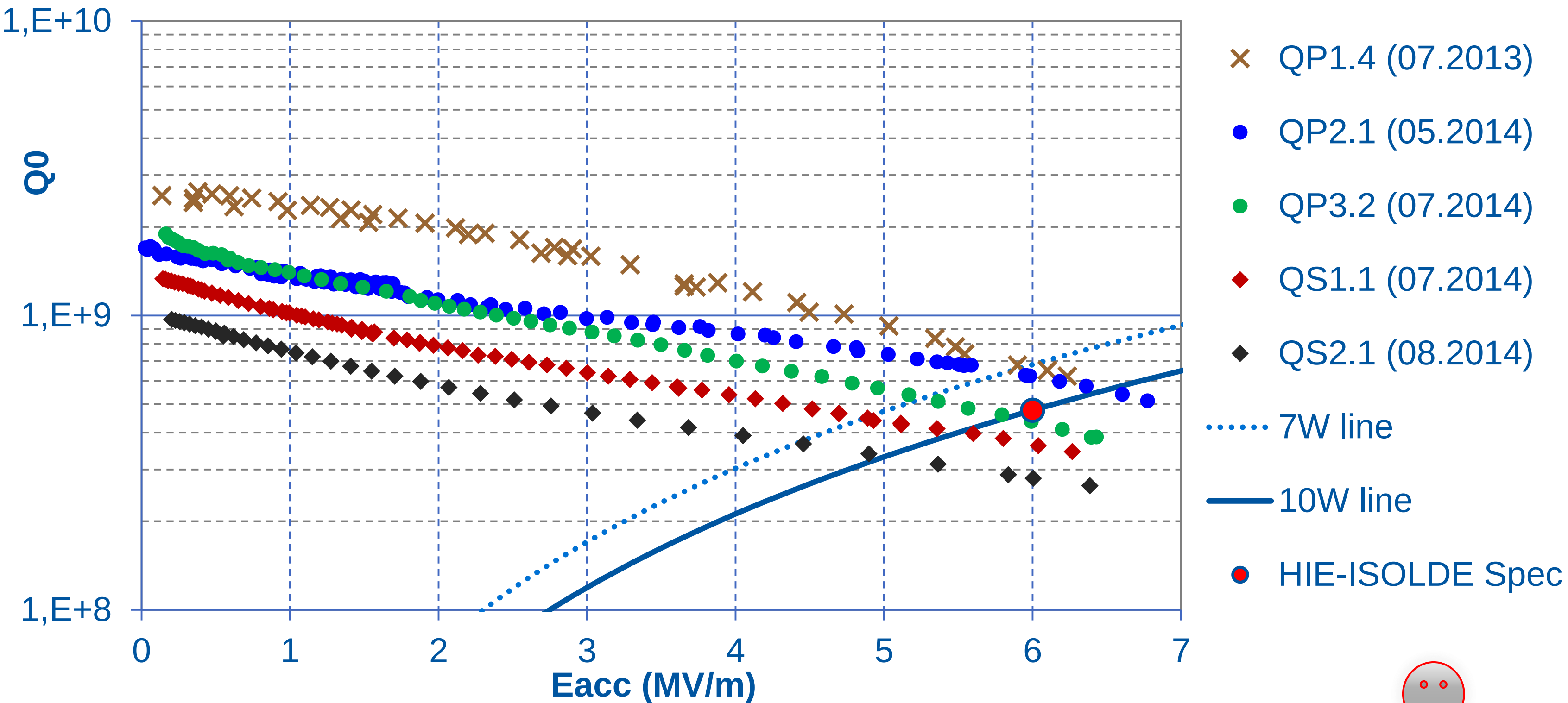
Nb-cathode power: 8kW

Cavity bias: -80V

Temperature:
Inner: from 315°C to 620°C
Outer: from 300°C to 430°C

14 runs: 25' coating + 5h35' cool down to 300°C each, total coating time = 6h

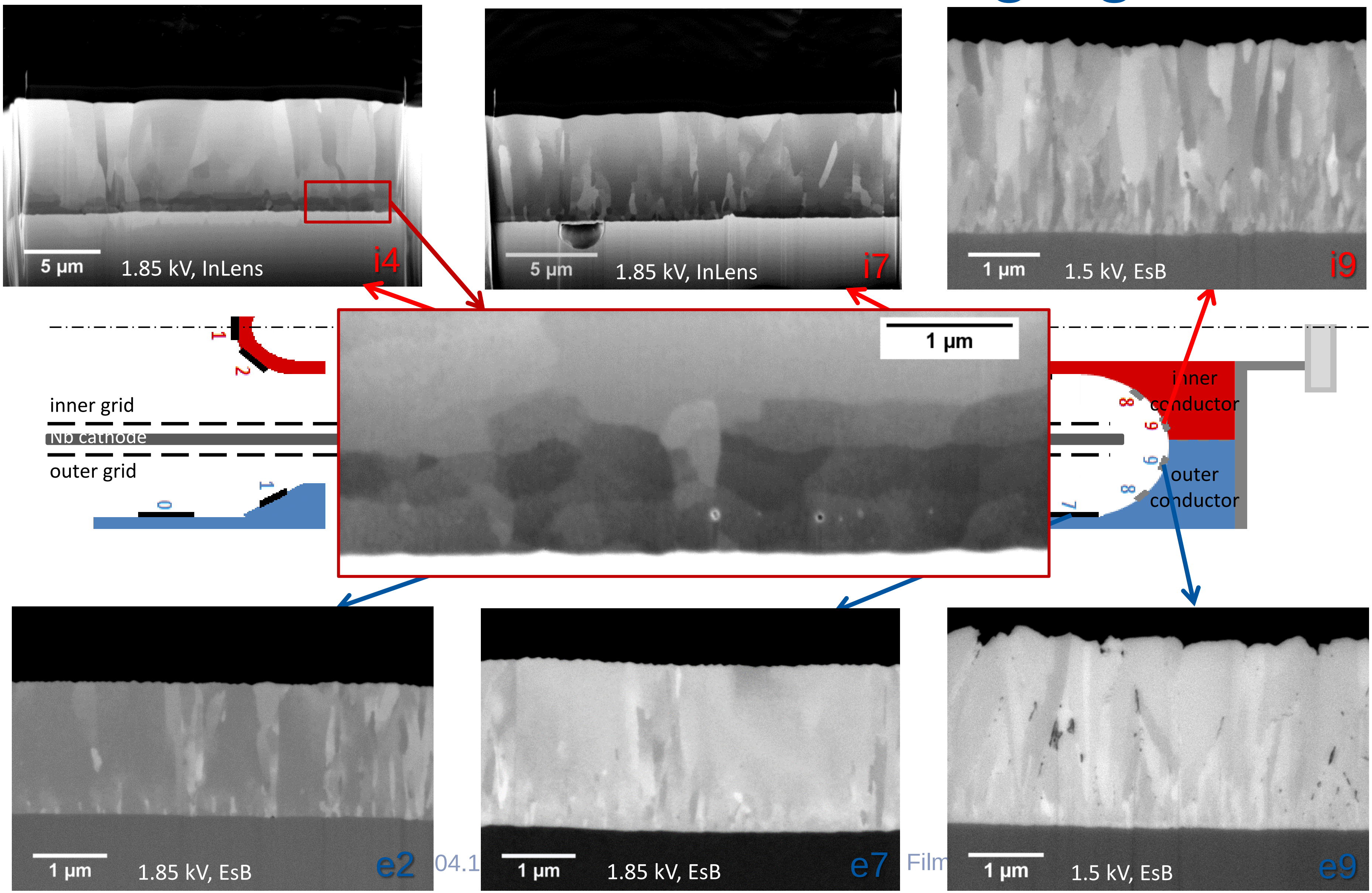
Cavities performances



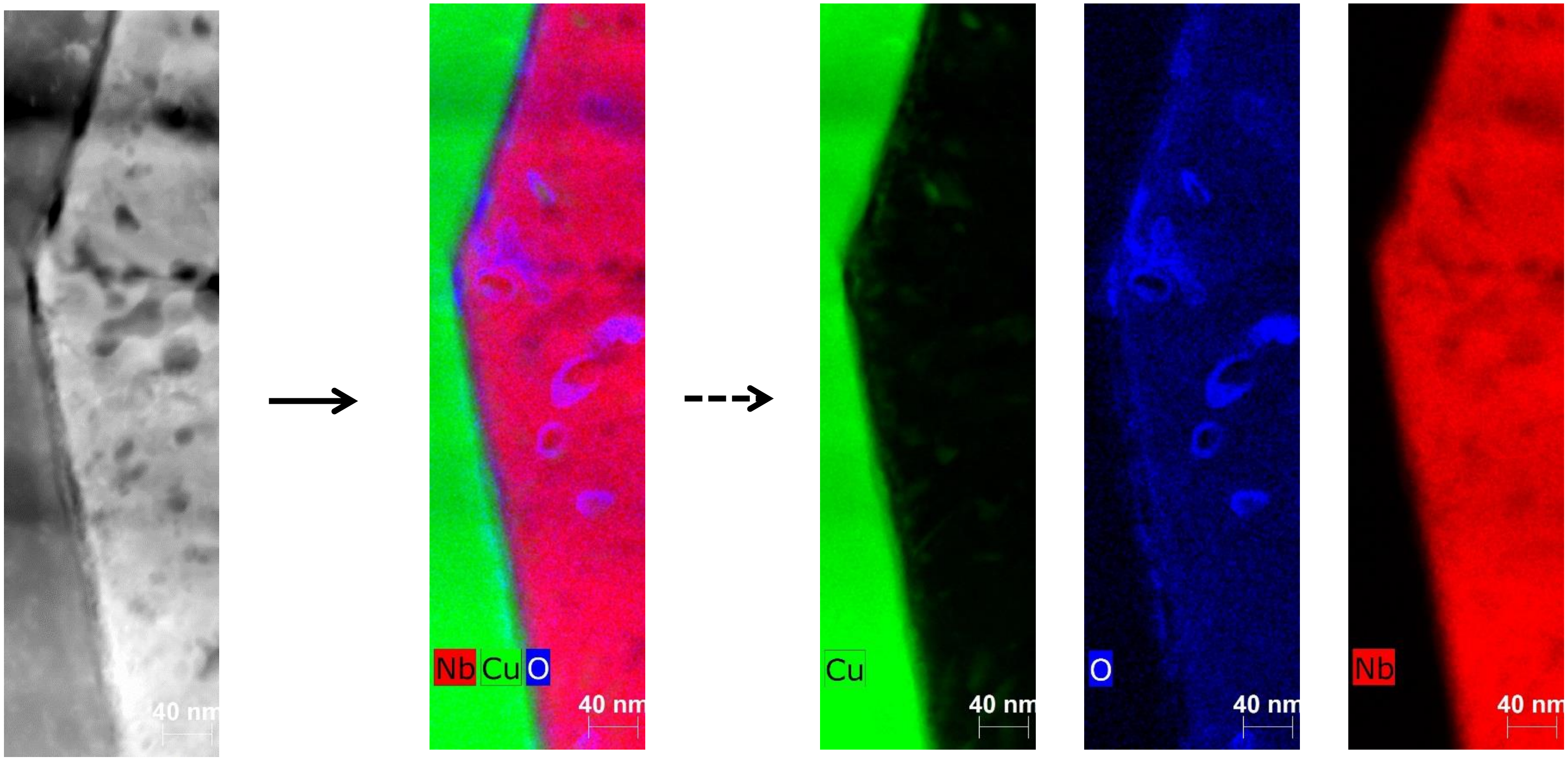
Eacc=6MV/m	HIE-ISOLDE specifications	QP1.4 test Prototype	QP2.1 Prototype 2	QP3.2 Prototype 3	QS1.1 pre-Serie	QS2.1 pre-Serie
Q0	4.7E+08	6.51E+08	6.23E+08	4.37E+08	3.61E+08	2.80E+08
Pcav(W)	10	7.5	7.6	10.8	12.5	17.0

for cryomodule, avg = 12 W

FIB-SEM cross section imaging

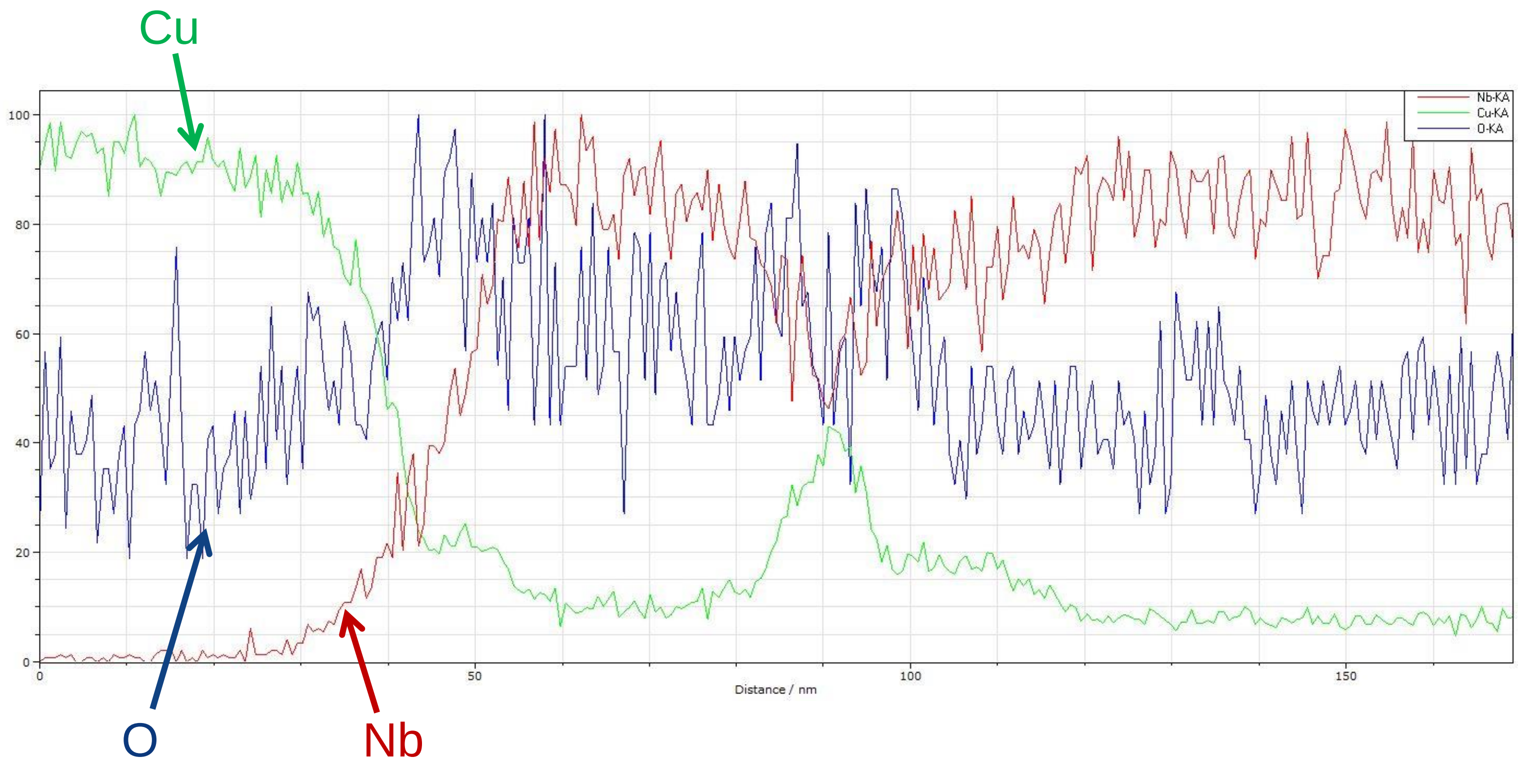


e9 EDS at Cu/Nb interface



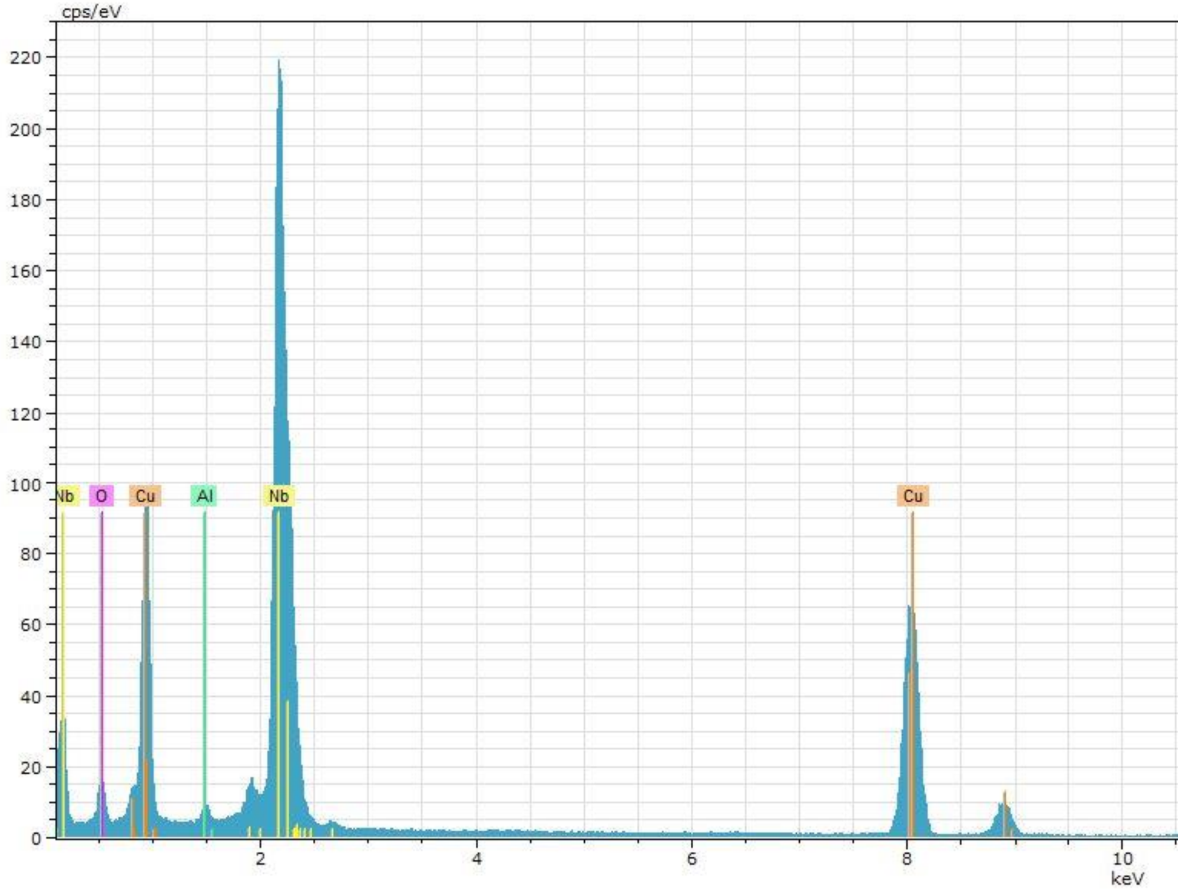
- Detailed mapping at the interface revealed presence of max 20 nm sized Cu precipitates.
- The precipitates are randomly scattered along the Cu/Nb interface and were found up to 200 nm far from the interface.
- Oxygen enrichment at the interface and around the porosity is detected.

Line scan along the interface



- Line scan shows the O enrichment at the interface and around the precipitate.
- Presence of Cu precipitate is confirmed

Precipitate EDS spectra



- The spectra was taken from the area marked with the red circle, the composition corresponds to Nb70Cu28Al2 in at.%. The peak of Al comes from TEM holder.

The influence of cooldown conditions at Tc on the Q0 of niobium sputtered quarter-wave resonators

Pei Zhang

M. Therasse and W. Venturini Delsolaro

(BE-RF-SRF, CERN)

*This work received support from a Marie Curie Early Initial Training Network Fellowship of the European Community's 7th Programme under contract number PITN-GA-2010-264330-CATHI.

Outline

- **Brief introduction of HIE-ISOLDE & QWR**
- **The impact of thermal gradient & cooldown speed**
- **The impact of ambient magnetic field**
- **The frequency shift during transition**
- **The impact of helium processing on low-field Q0**

Cavity production flow

Cavity reception
↓
Frequency tuning
↓
Surface treatment
↓
Niobium coating
↓
Cryostat preparation
↓
RF cold test
↓
Cavity storage

Niobium Stripping

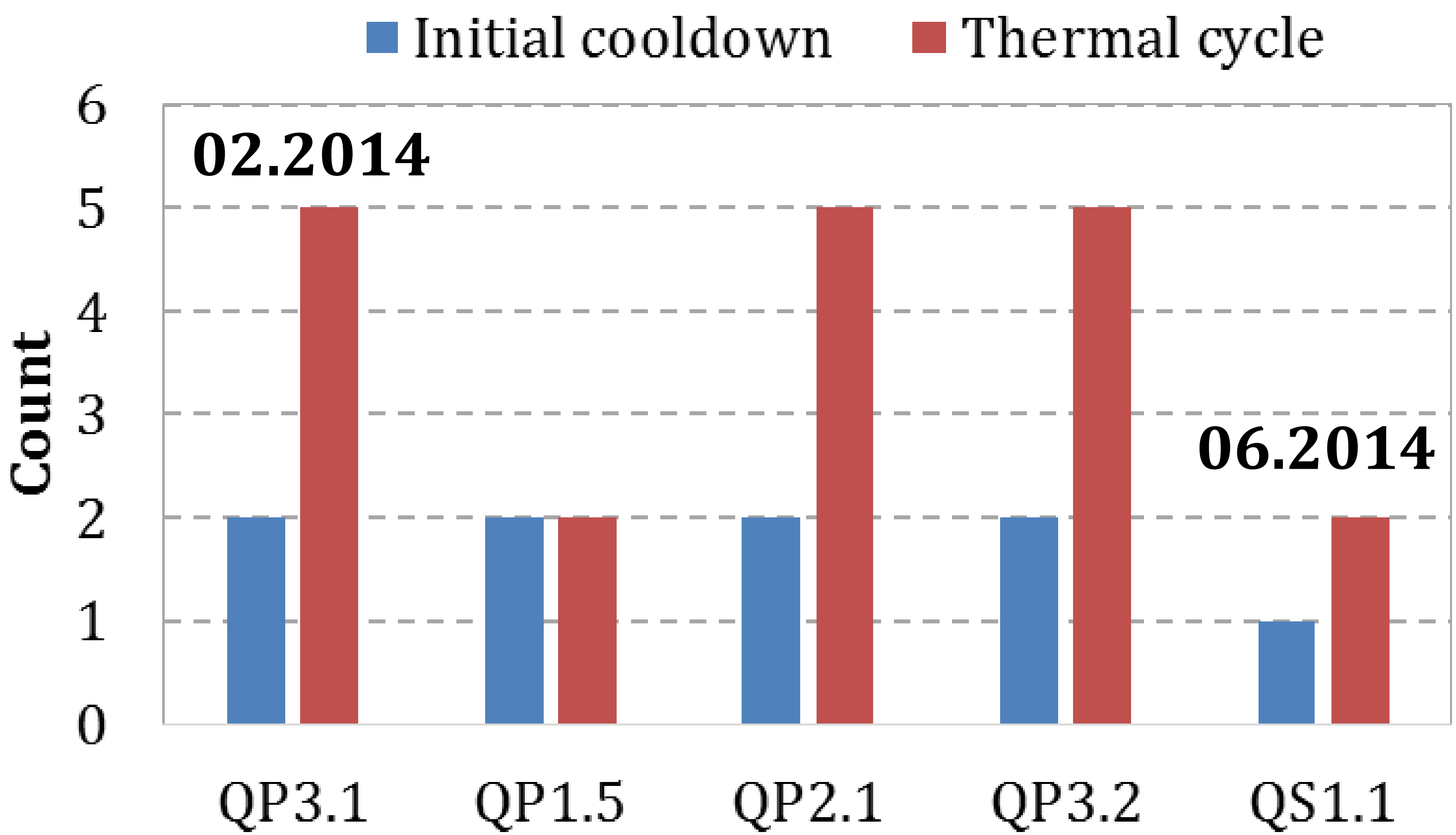
4-week process

More on A. Sublet's talk

From Feb to Jun 2014

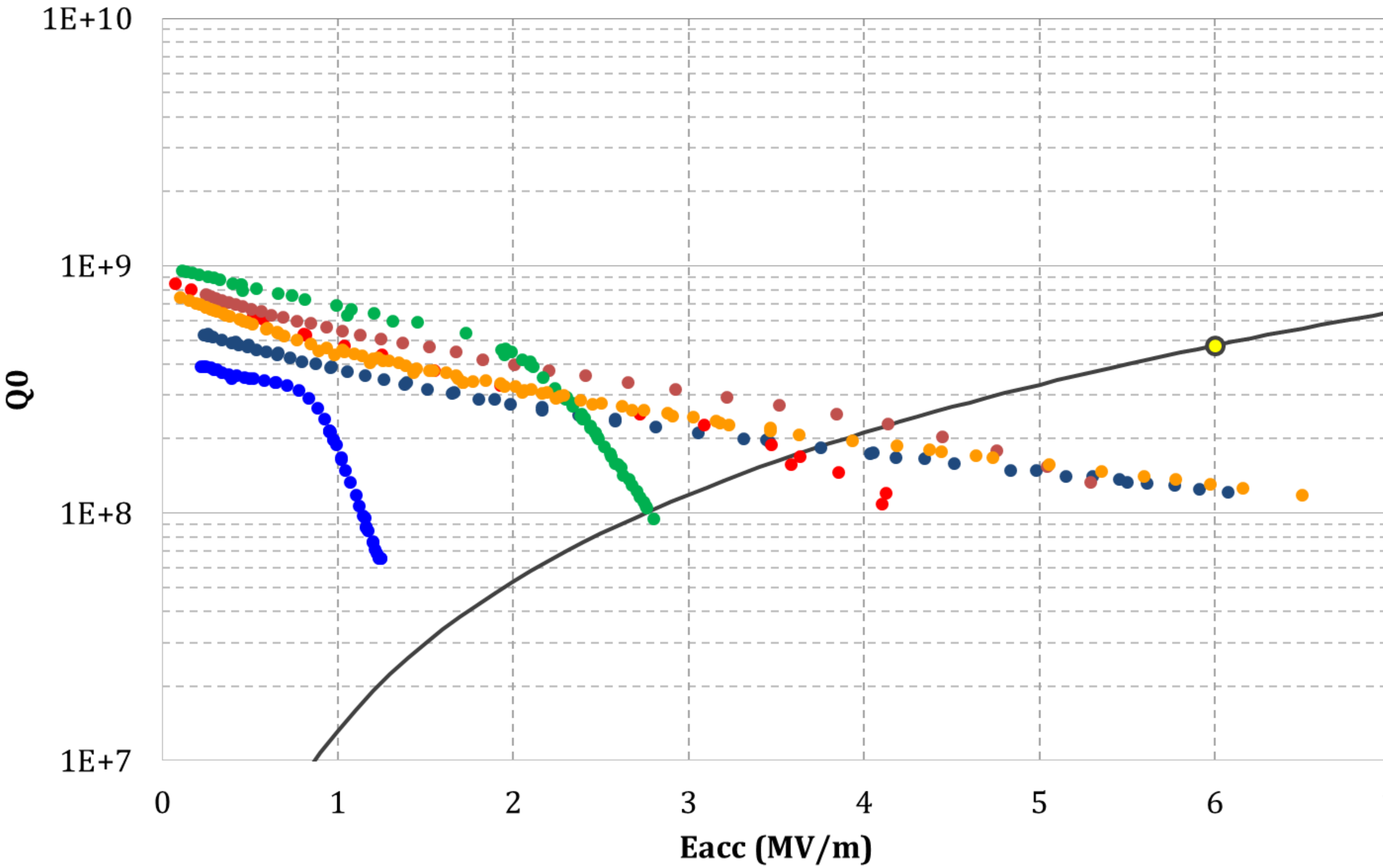
Initial cooldown: two full days

Thermal cycle: one day

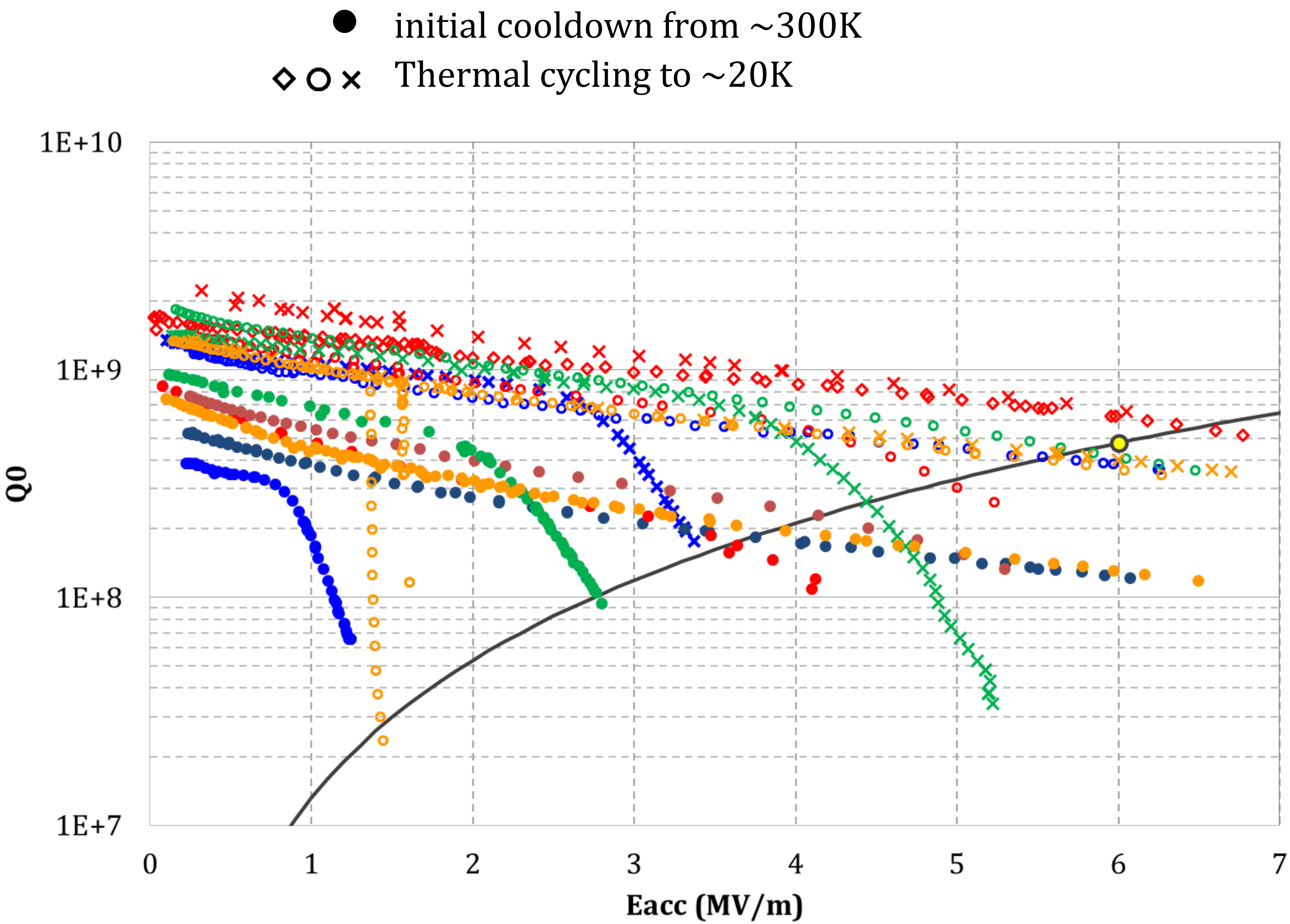


Initial cooldown

- initial cooldown from ~300K



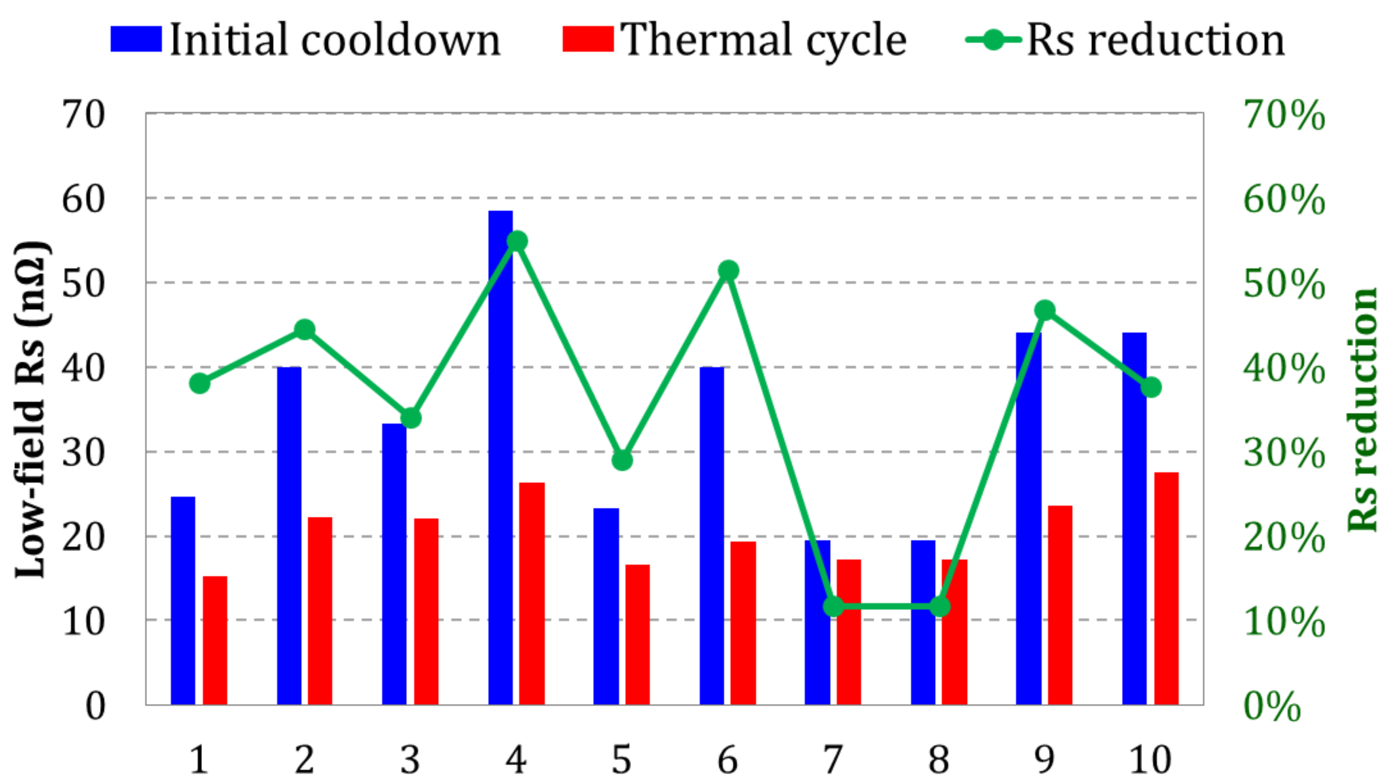
Initial cooldown & thermal cycle



Low-field Q0 improvement

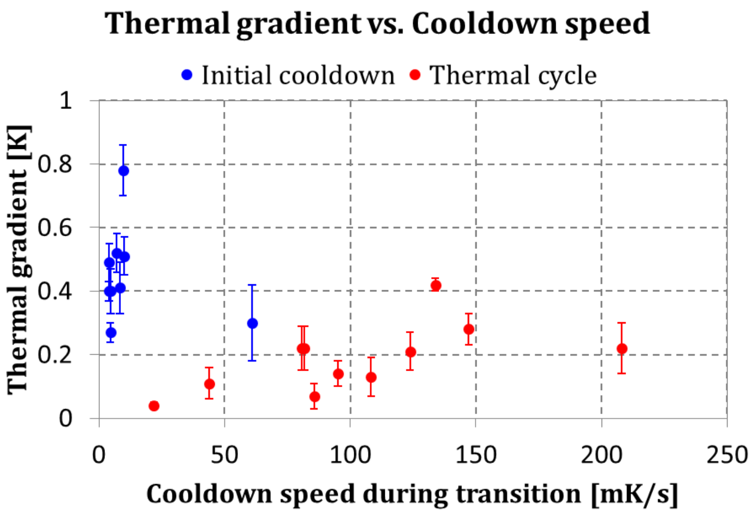
The reduction of low-field Rs by thermal cycle

12% ~ 55%



Low-field: Eacc = 0.2 MV/m

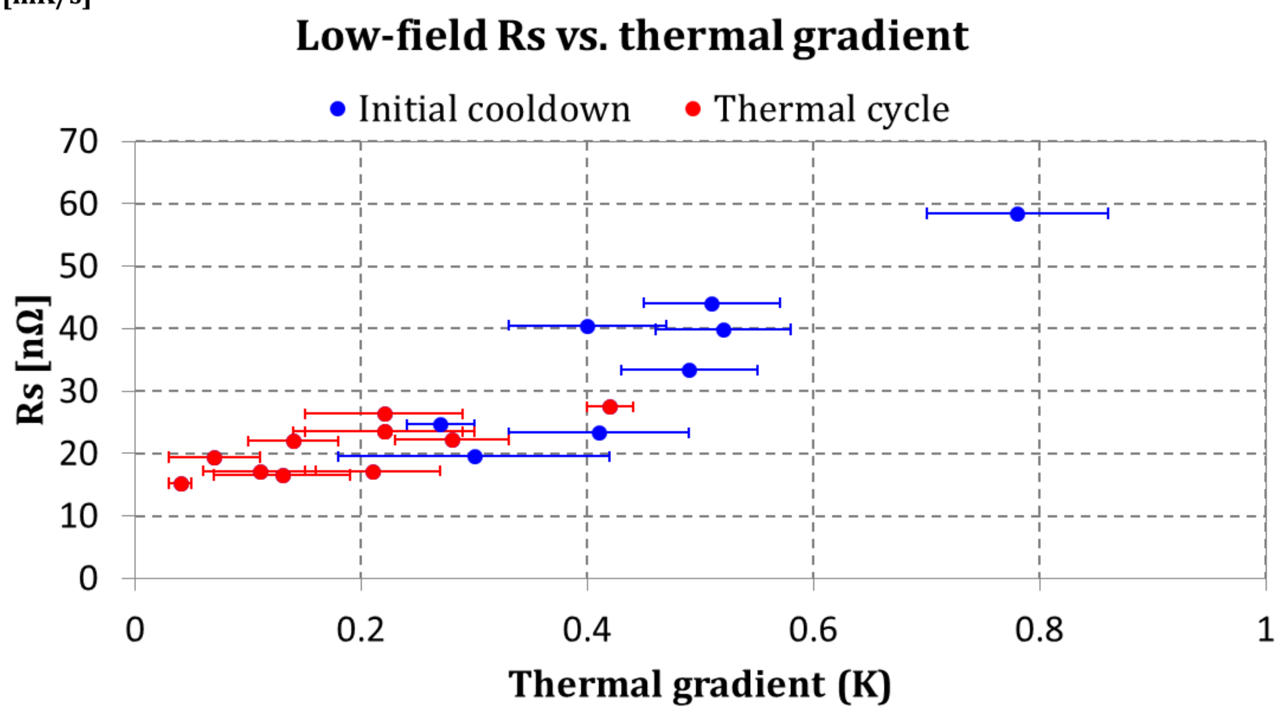
Rs vs. thermal gradient



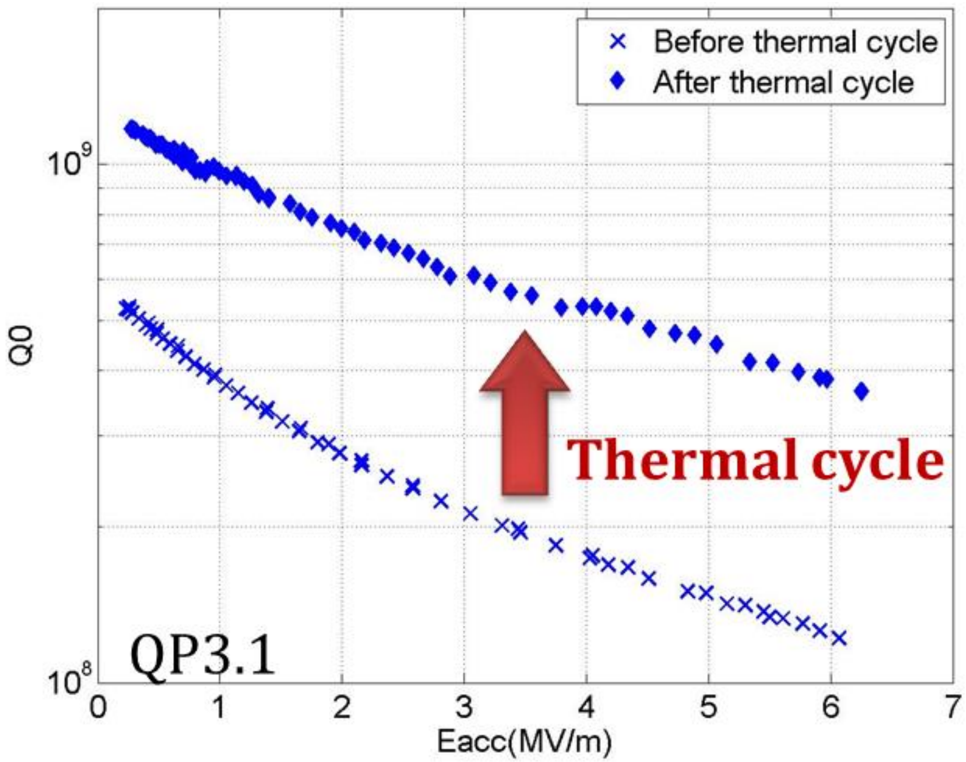
Low-field: Eacc = 0.2 MV/m

$$Rs = \frac{30.8\,\Omega}{Q_0}$$

Clear dependence on thermal gradient



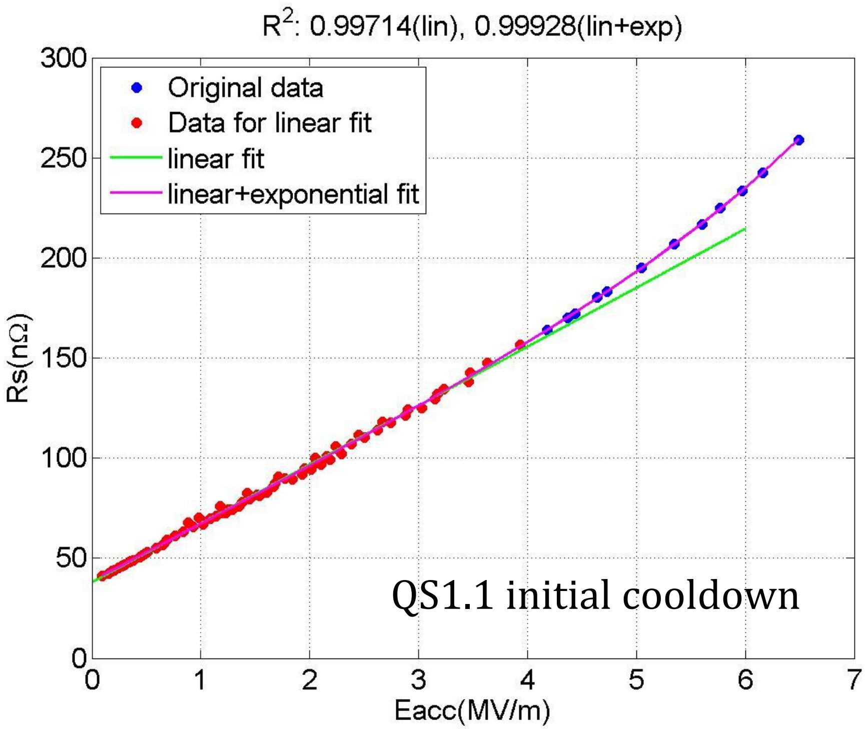
Decompose Rs



Residual resistance

$$Rs = Rs0 + Rs1 \cdot E_{acc}$$

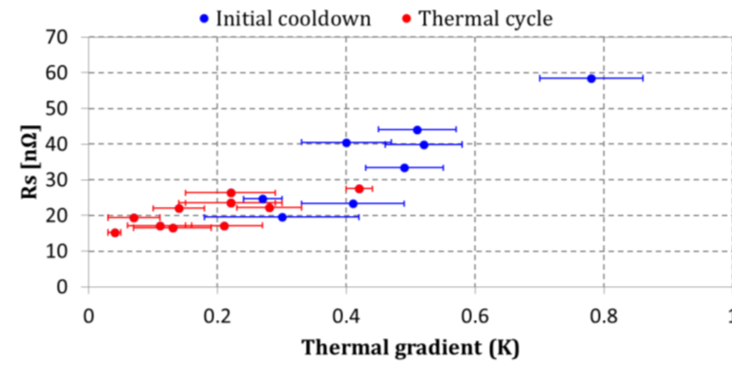
Linear slope



Summary

Thermal gradient

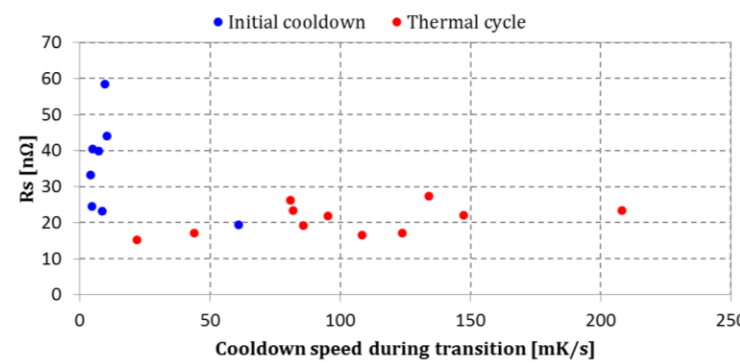
Clear dependence



Q0

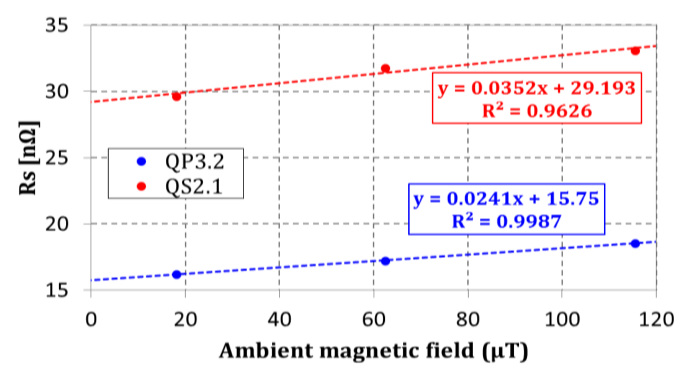
Cooldown speed

Insensitive



Ambient B-field

0.035 nΩ/μT



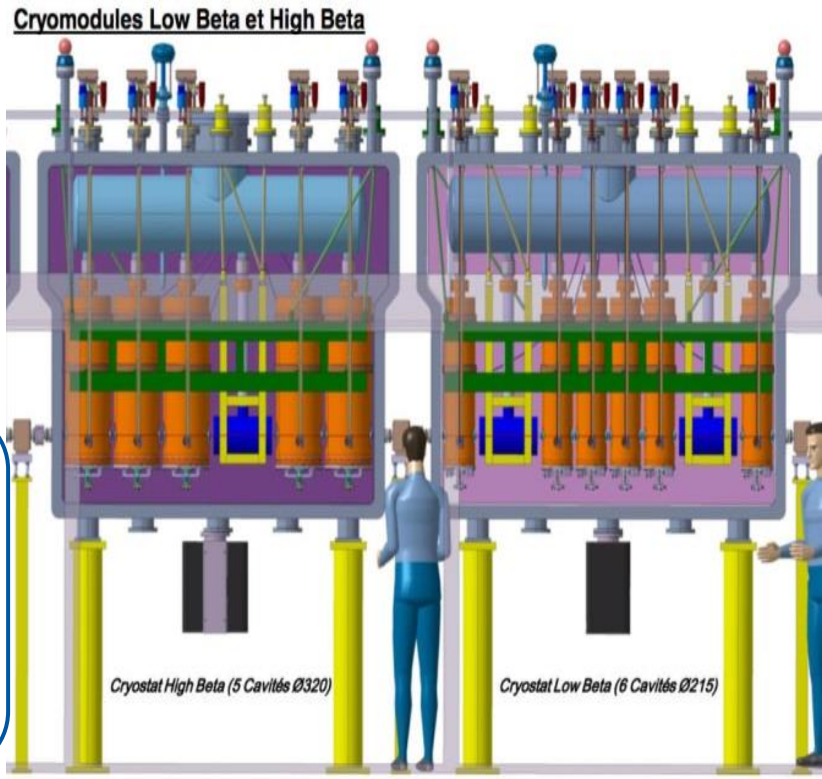
ISTITUTO NAZIONALE DI FISICA NUCLEARE
LABORATORIO NAZIONALE DI LEGNARO
Laboratorio di Superconduttività

STATUS AND DEVELOPMENTS OF SPUTTERED Nb/Cu QWRs AT LNL-INFN

D. Franco Lespinasse, G. Keppel, S. Stark, A.A. Rossi, A.M. Porcellato, F. Stivanello, C.Pira and V. Palmieri

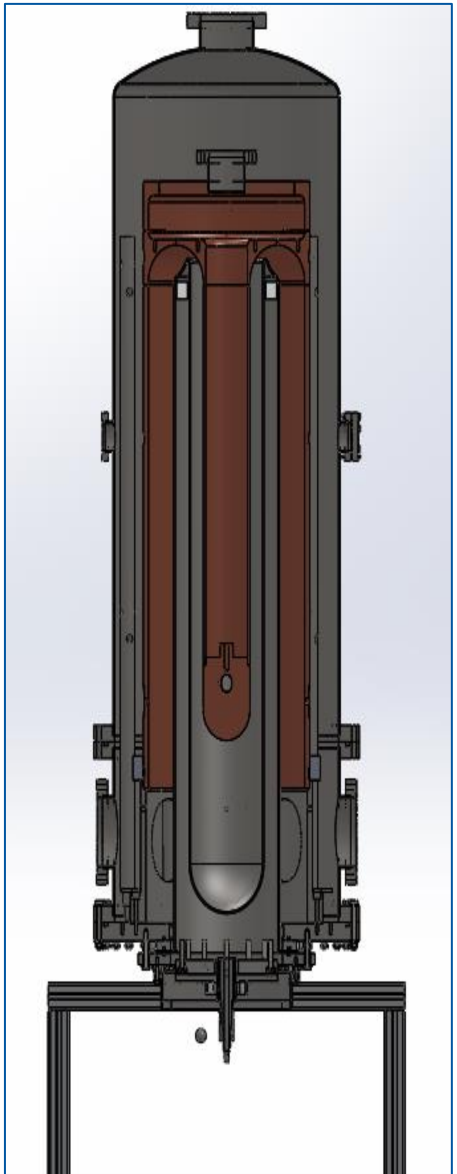
THIN FILMS AND NEW IDEAS FOR SRF
OCTOBER, 2014

Framework



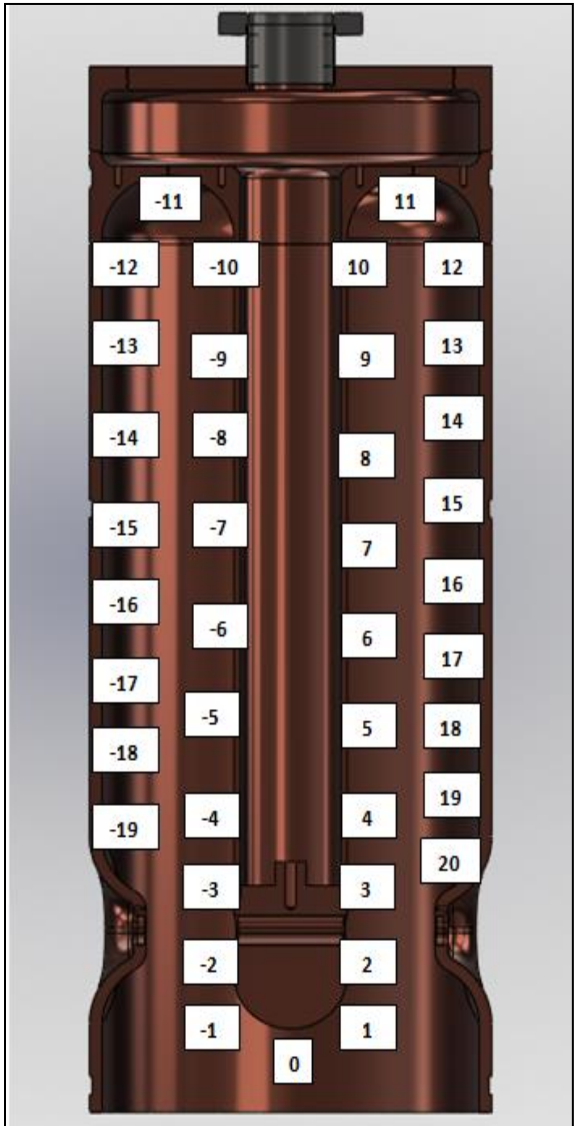
Cavities with accelerating field of 6 MV/m with a Q-value of at least $5X10^8$

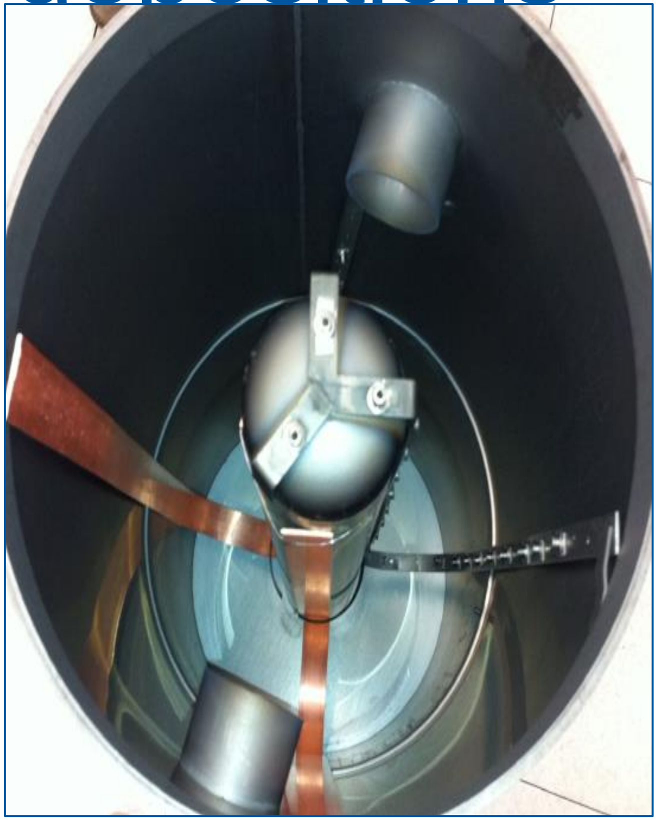
Magnetron sputtering vacuum system



Stainless steel cathode

Magnetron sputtering depositions

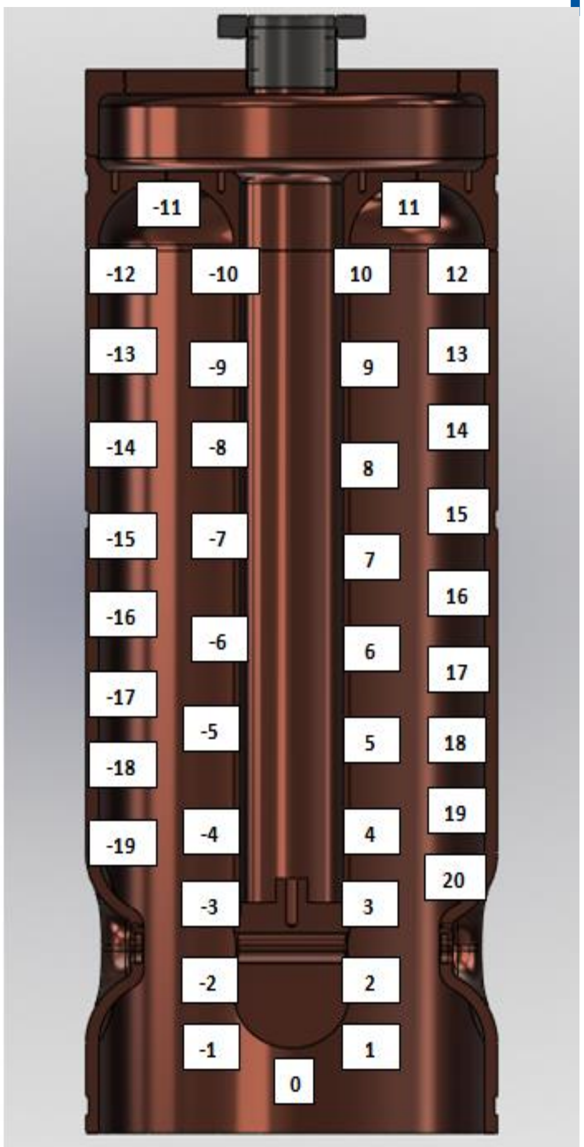


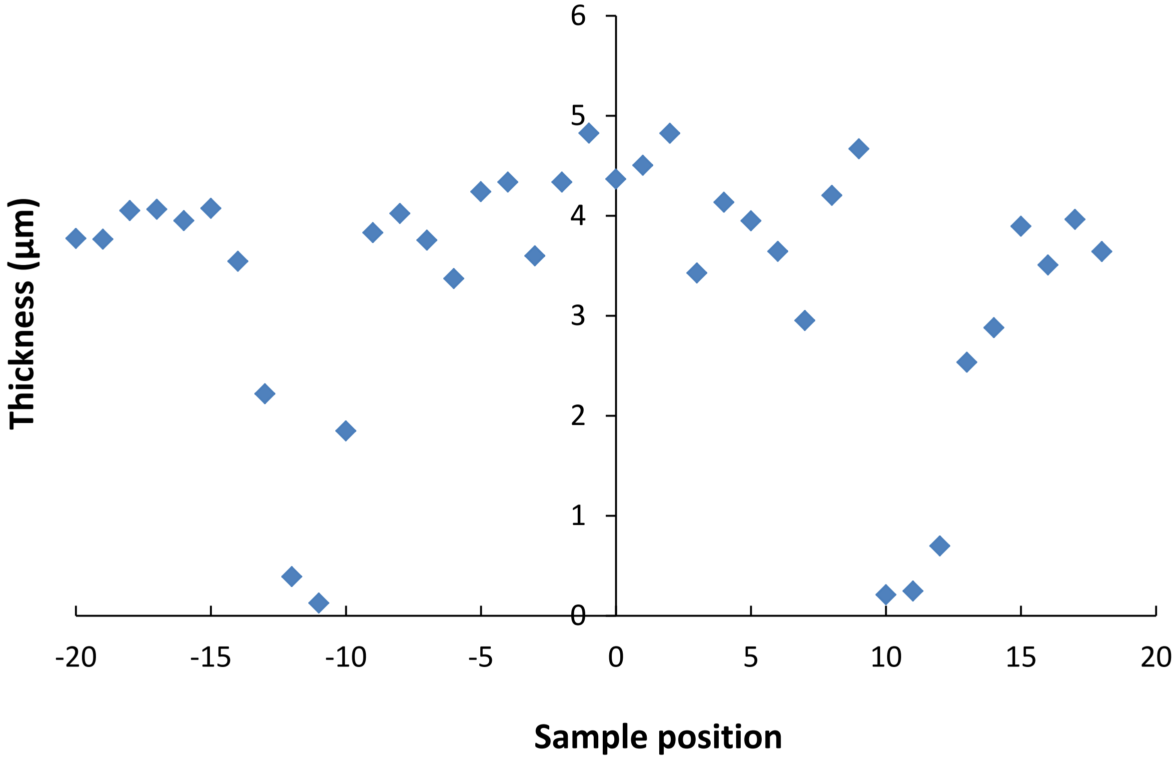


Stainless steel onto copper strips

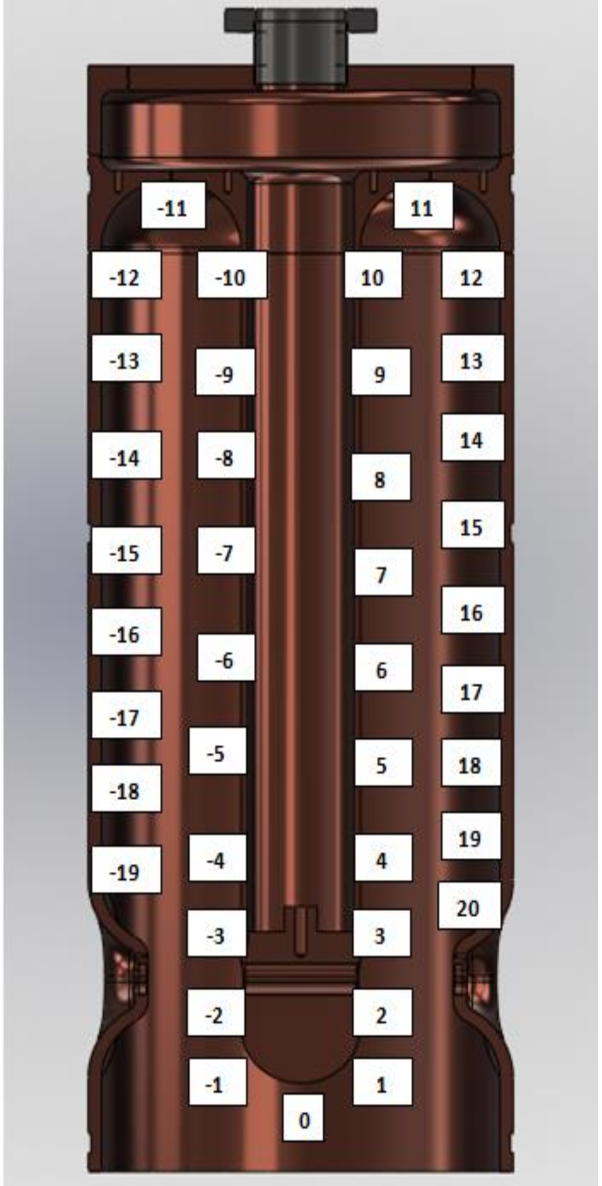
Stainless steel onto quartz samples

Magnetic field confinement

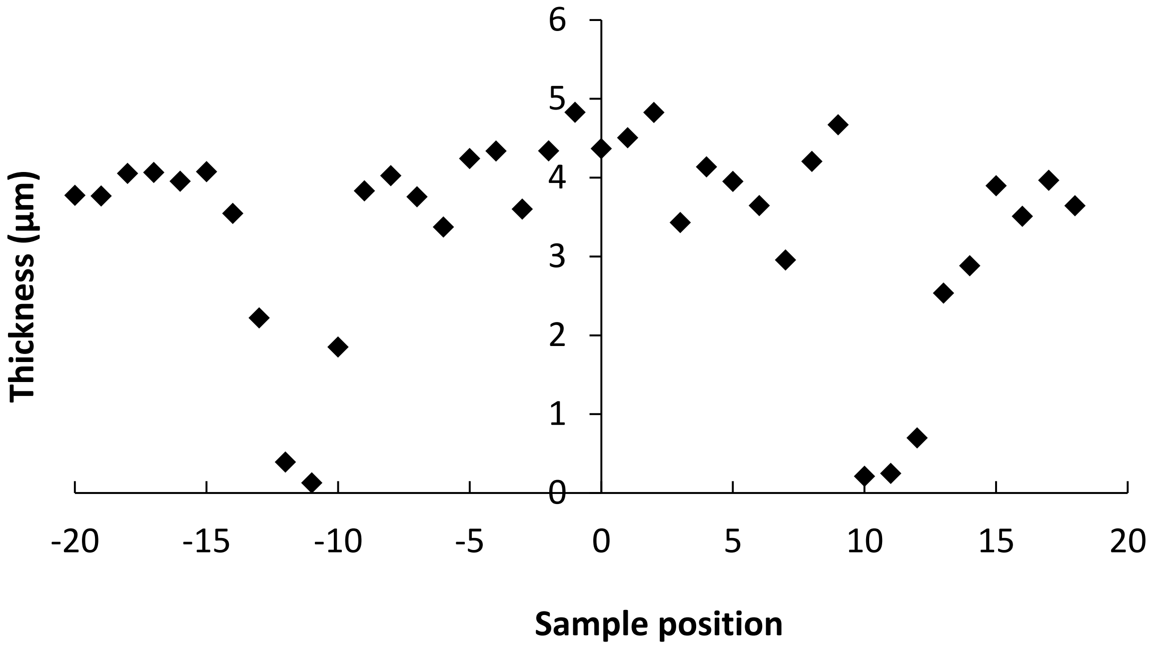




Thickness res

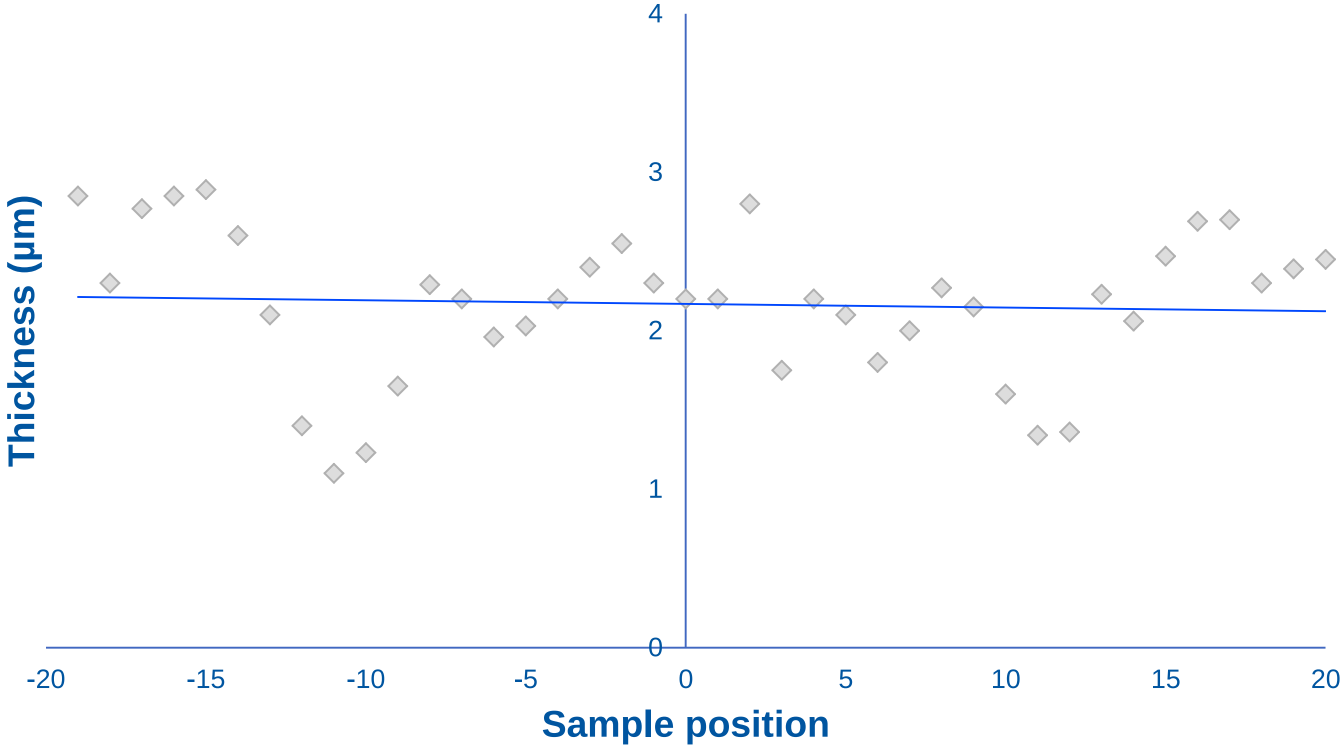


IV magnetic confinement



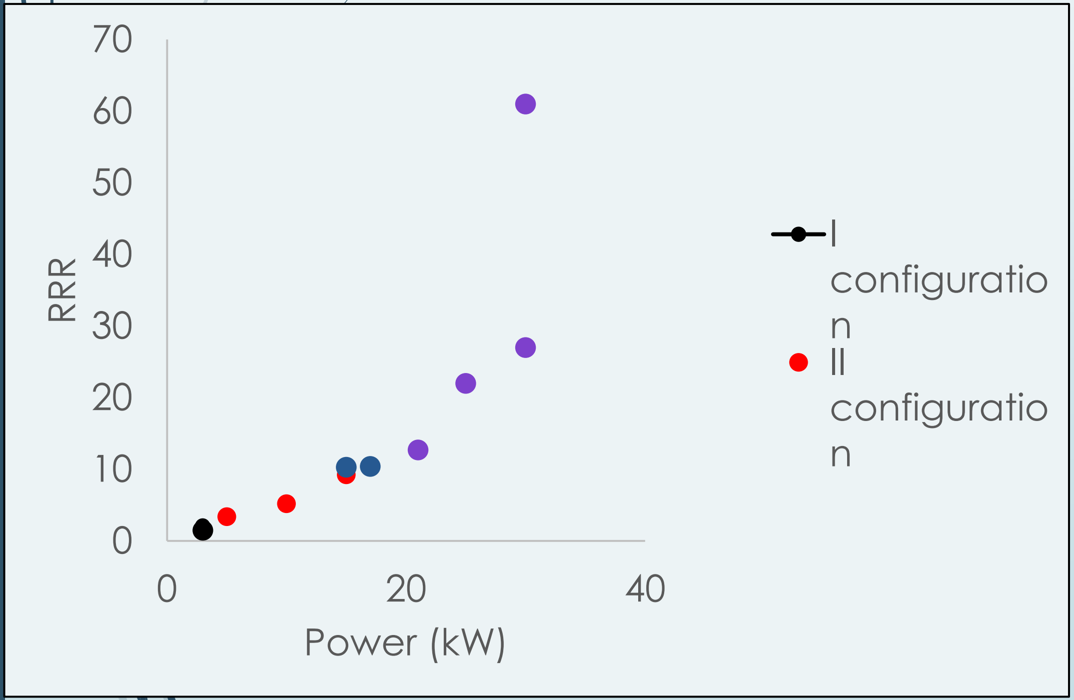
Thickness results

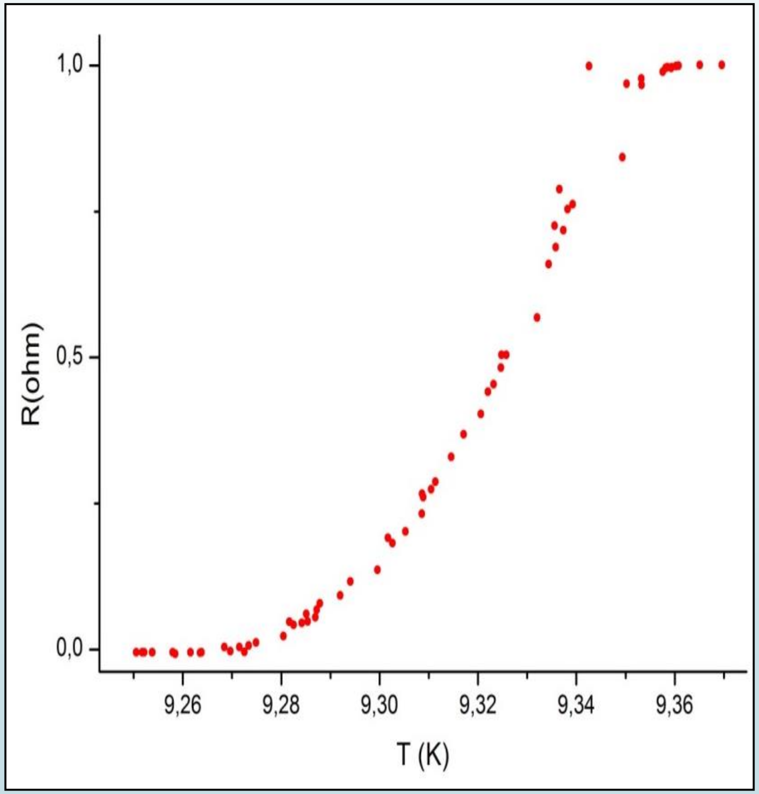
2±1 µm



Superconductive properties

- RRR and Tc measurements





Deposition of Nb/Cu QWR

- The sputtering process was carried out taking into account the following parameters:

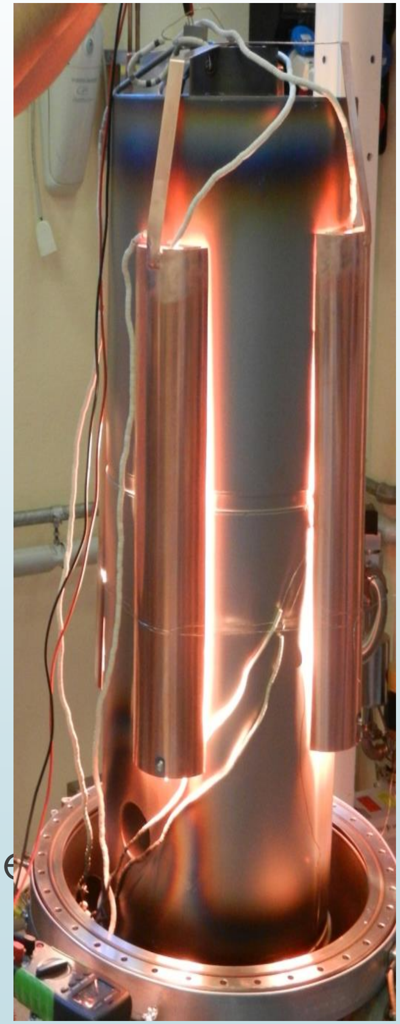
Power 30 kW
Voltage 408V
Sputt. Pressure $6x10^{-3}$ mbar
Current 72,57 A
Time 40 min

- S

Deposition of Nb/Cu QWR

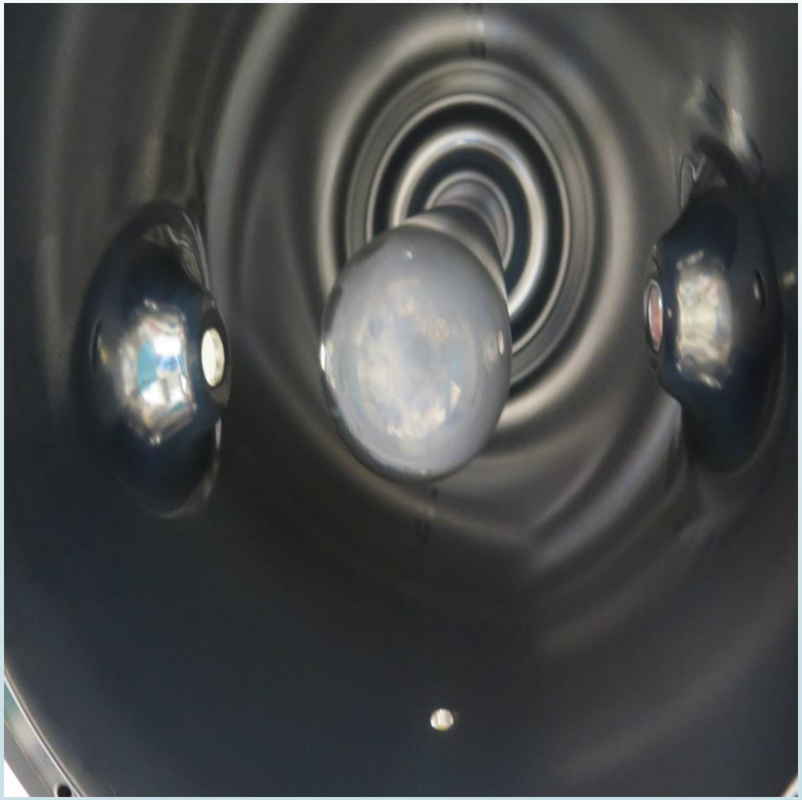
- **An important parameter:**

- The cavity was heated at **450°C** during the



Deposition of Nb/Cu QWR

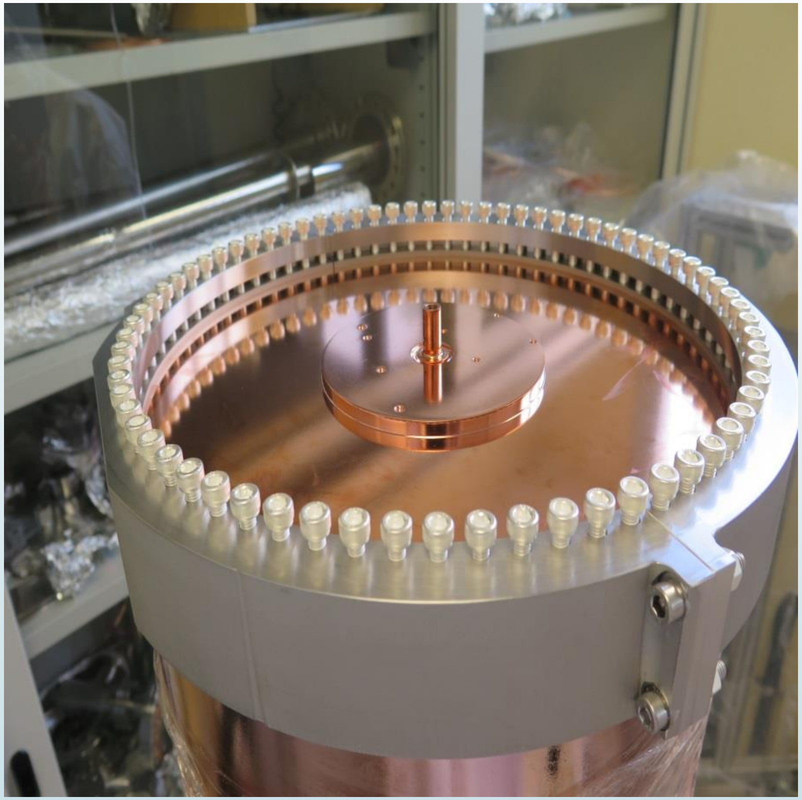
QWR after surface treatment (SUBU)



QWR after magnetron sputtering deposition

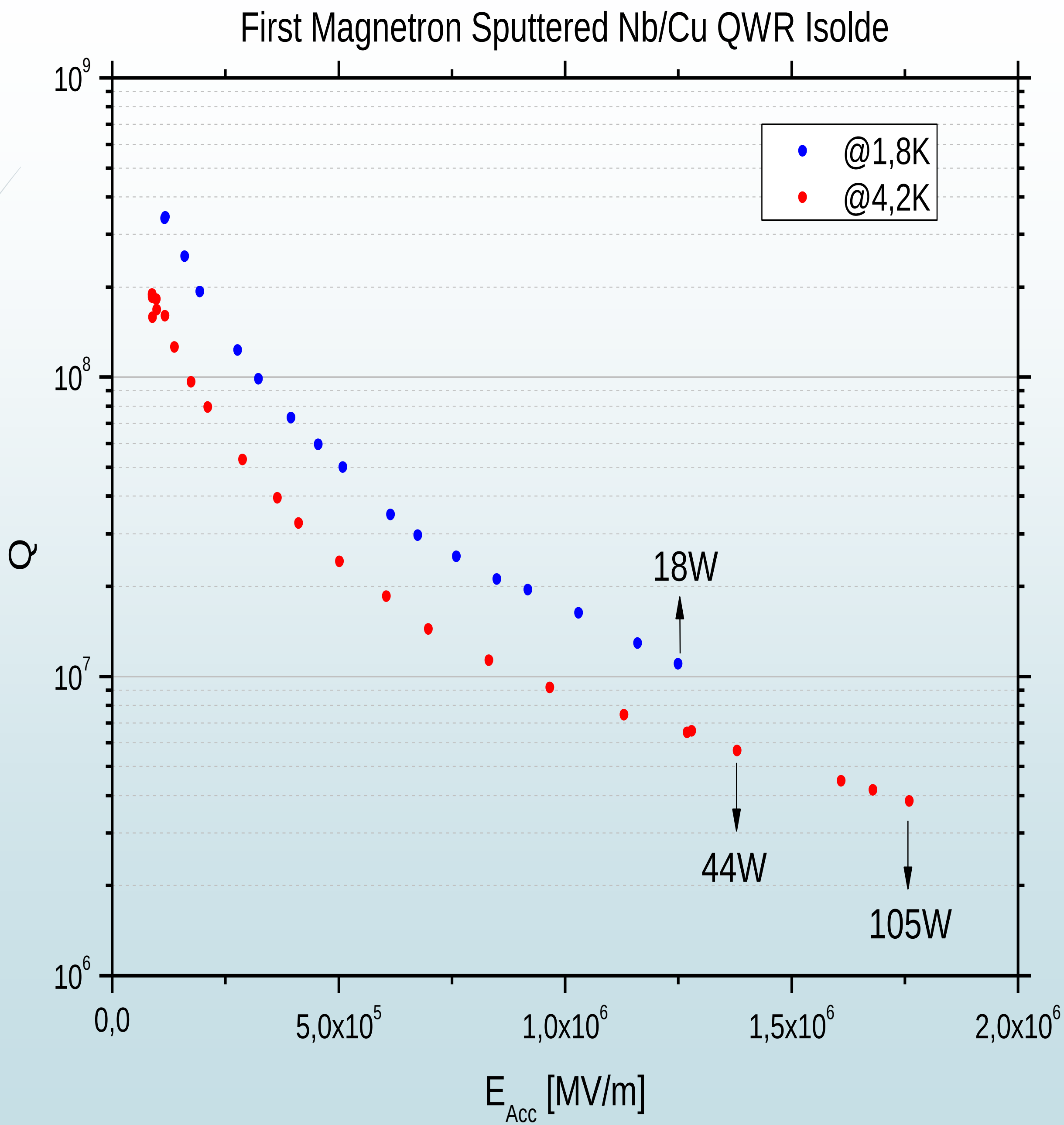
Cleaning and mounting

High pressure
rinsing
100 bar



Cavity
during the
Nb/Cu
plate

Test cryostat



First Magnetron Sputtered Nb/Cu QWR Isolde
@1,8K
@4,2K
18W
44W
105W
Q
E_Acc [MV/m]
0,0
5,0x10^5
1,0x10^6
1,5x10^6
2,0x10^6
10^9
10^8
10^7
10^6

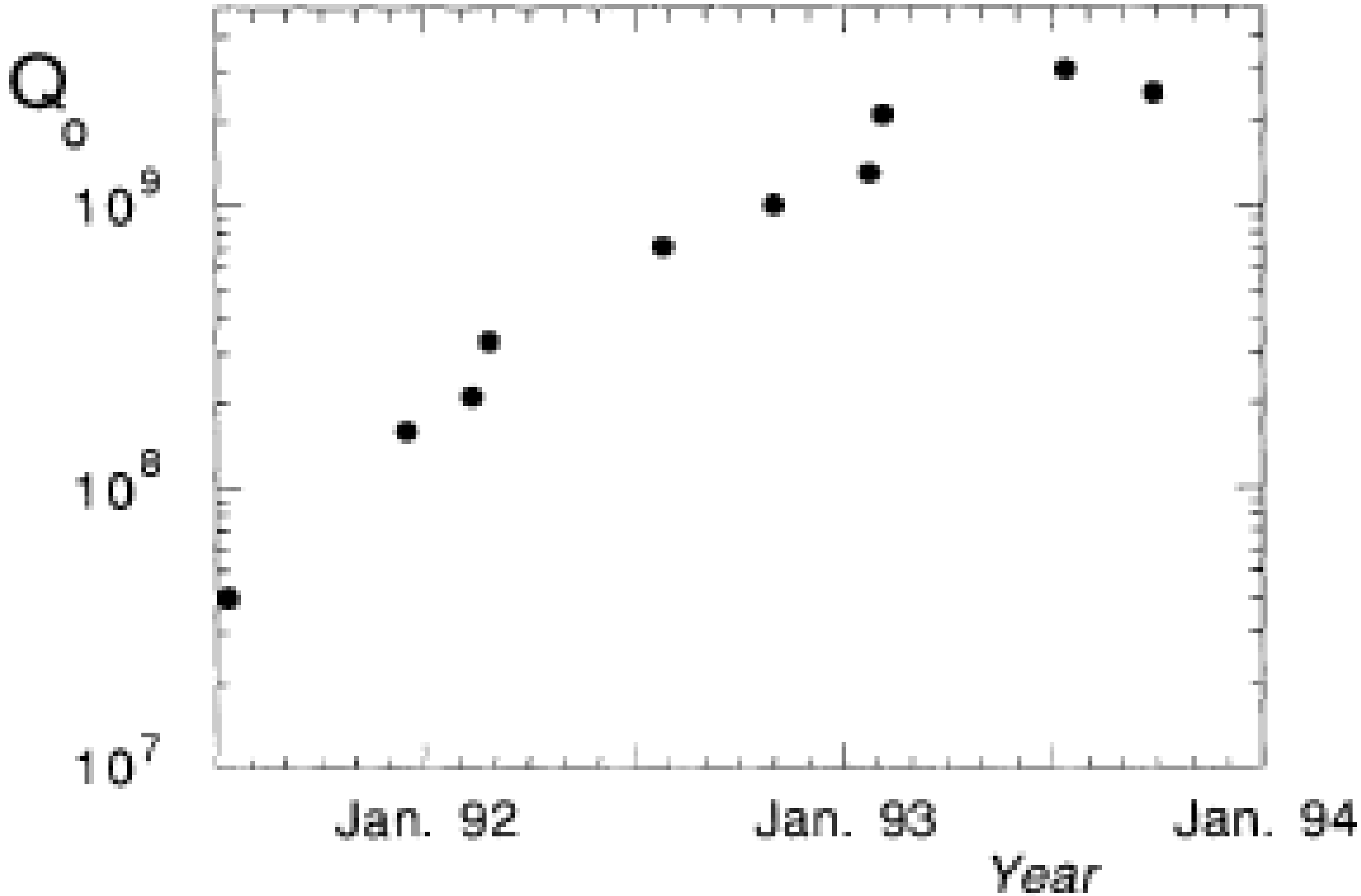


Fig. 2. Q-value at zero field versus the date of prototype production.

Energetic Condensation Growth of Nb and other Thin Films for SRF Accelerators

Mahadevan Krishnan, Irfan Irfan, Steven Chapman, Katherine Velas and Matthew Worstell
Alameda Applied Sciences Corporation (AASC), San Leandro, California 94577

presented at

Thinfilms and new ideas for SRF

October 6-8, 2014

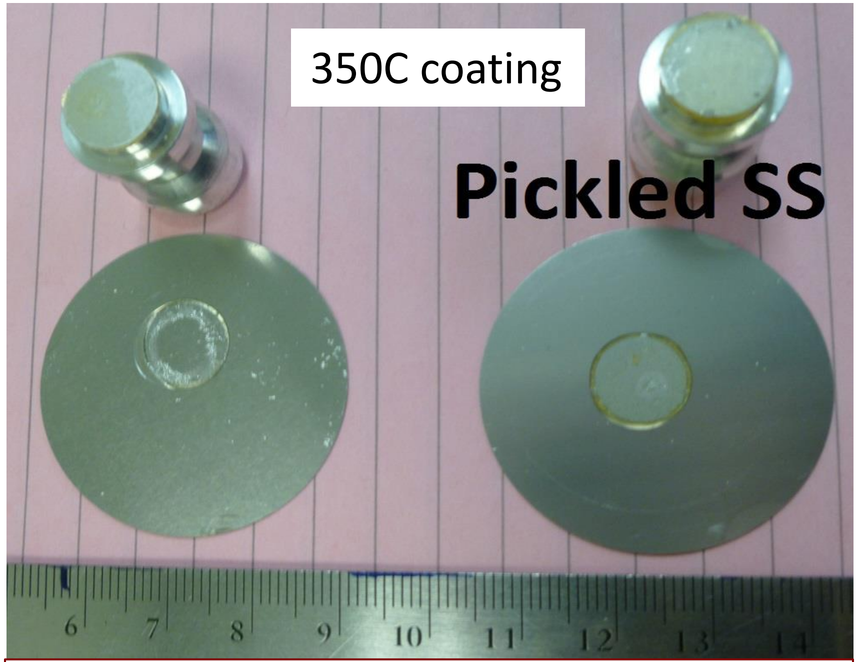
Collaborators:

Fermi Lab.	Curtis Crawford, Anna Grasselino, Lance Cooley
Los Alamos National Lab.	T. Tajima, L. Civale
Helmholtz-Zentrum Berlin für Materialien und Energie GmbH	O. Kugeler, Raphael Kleindienst, Jens Knobloch
CERN	Sarah Aull
Research Instruments	Michael Pekeler

This research is supported at AASC by DOE SBIR Grants DOE Grants: #DE-SC0011371, DE-SC0011294, DE-SC0007678, DE-SC0004994 and DE-SC0009581

Nb on stainless steel bellows: temperature matters

- Coating of stainless steel with Nb film at 350C and at 550C



Images of Nb coated coupons (350C coating) after the DeFelsko pull-off tests. The IPA cleaned Nb film was detached at 30Bar while the pickled coating detached at 56 Bar (*with no Nb film detachment*)

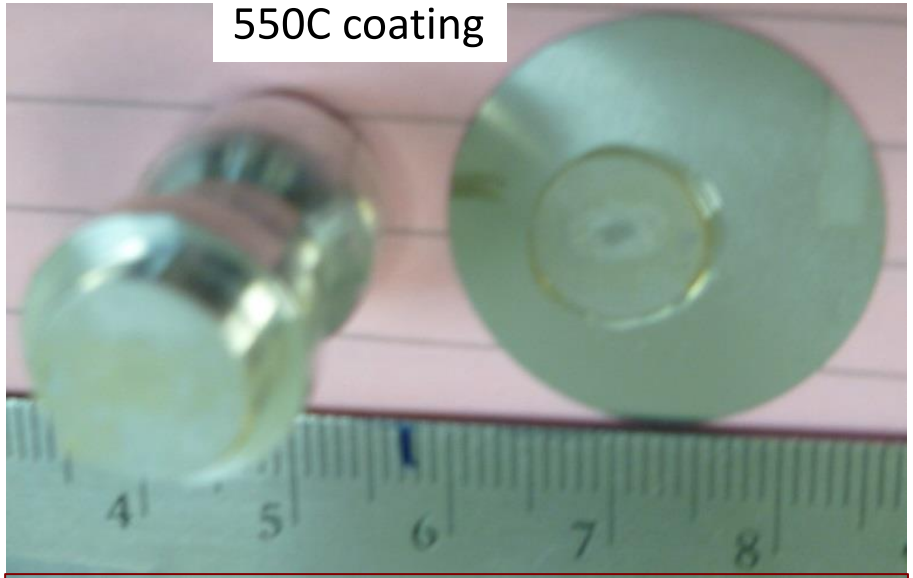
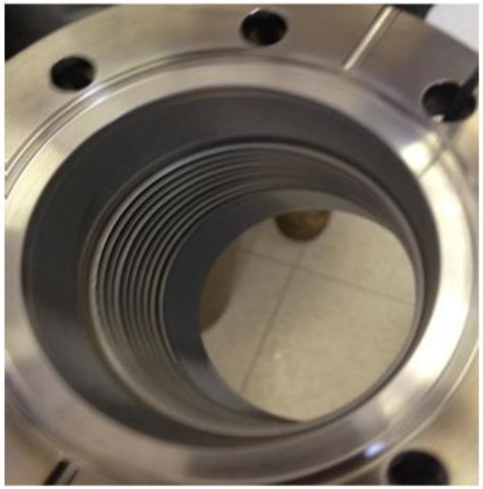


Image of Nb coated coupon (550C coating with only acetone/IPA cleaning) after the DeFelsko pull-off tests. The Al dolly detached at 56 Bar (*with no Nb film detachment*)

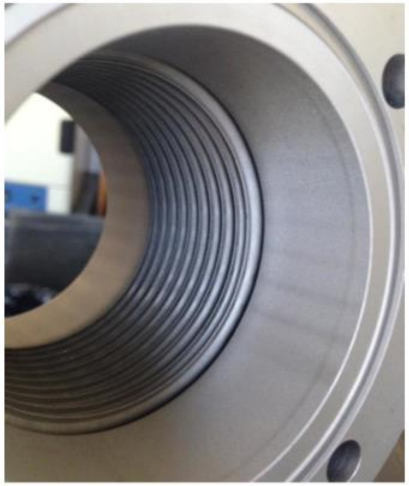
Nb on stainless steel bellows: LN_2 cold shock tests

- Courtesy of Sergey Belomestnykh & Binping Xiao of BNL



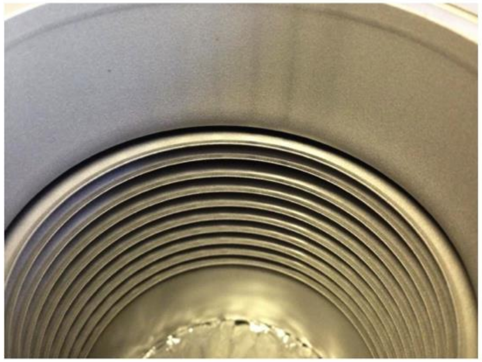
Nb on stainless steel bellows

before cold test



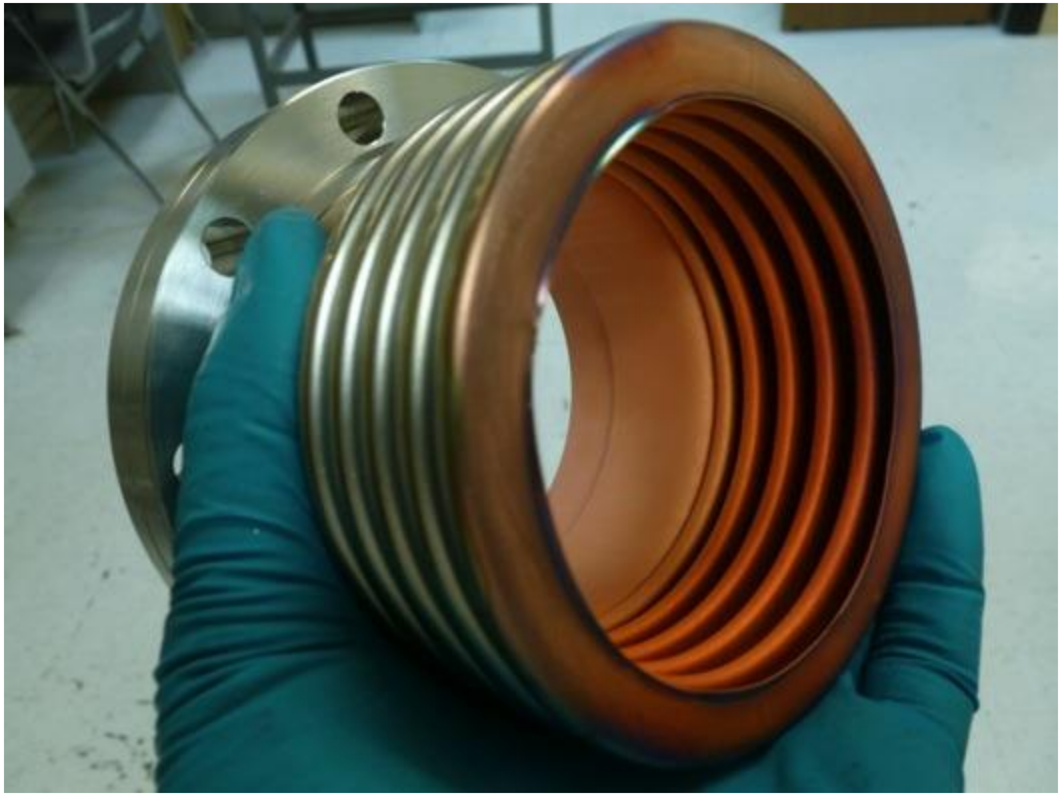
Nb-on-Cu-on stainless steel bellows

after cold test: 3 dips (overnight)



- BNL reports that the Nb films adhered very well to the stainless steel; mechanical flexing tests are in progress, to be followed by RF tests

Status of AASC Process: bellows coating



Stainless steel bellows coated with a ~45µm Cu film using the AASC CED process

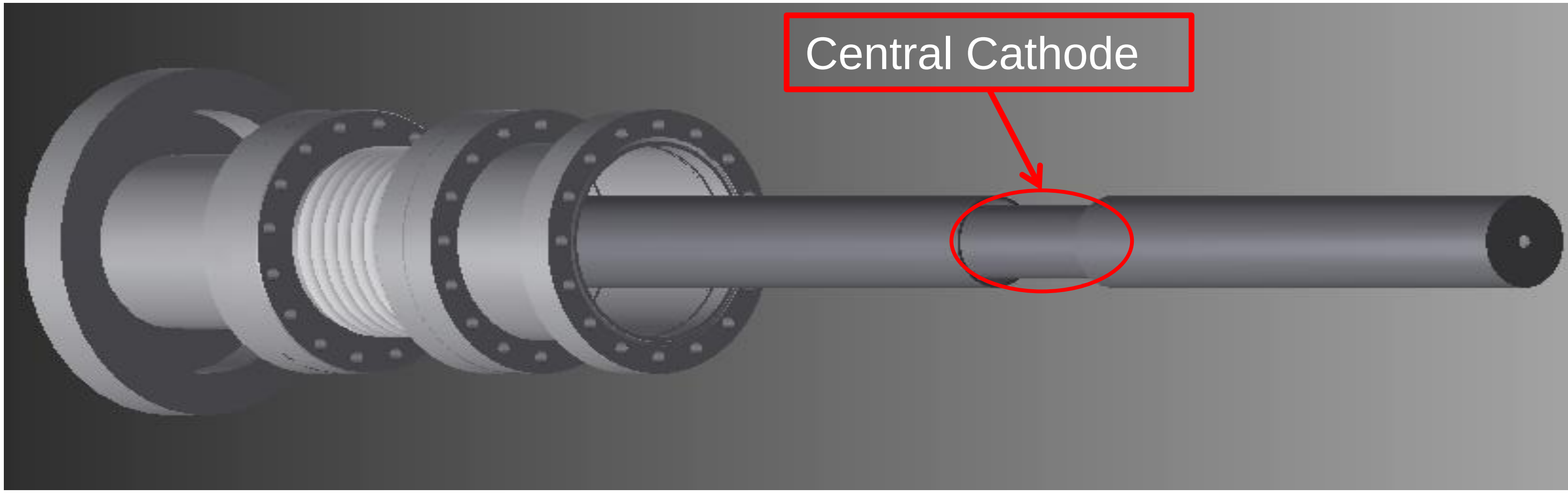
CED process coats irregular surfaces such as bellows

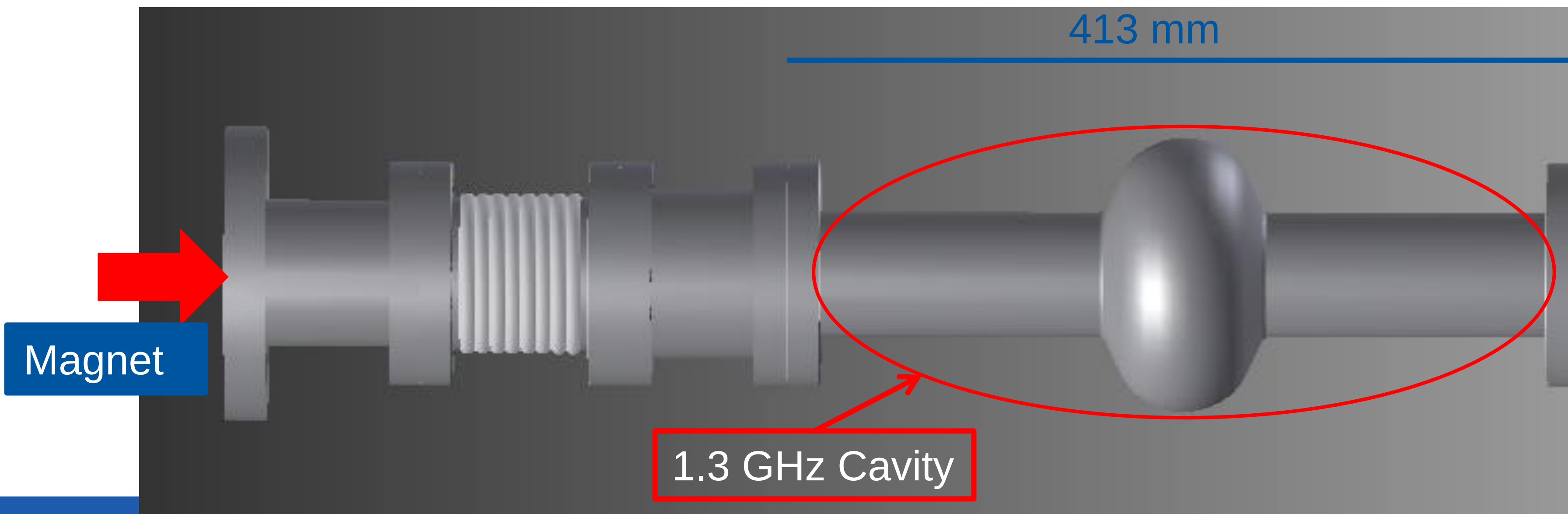
Development of HIPIMS Technology for Superconducting Coated Cavities

CERN

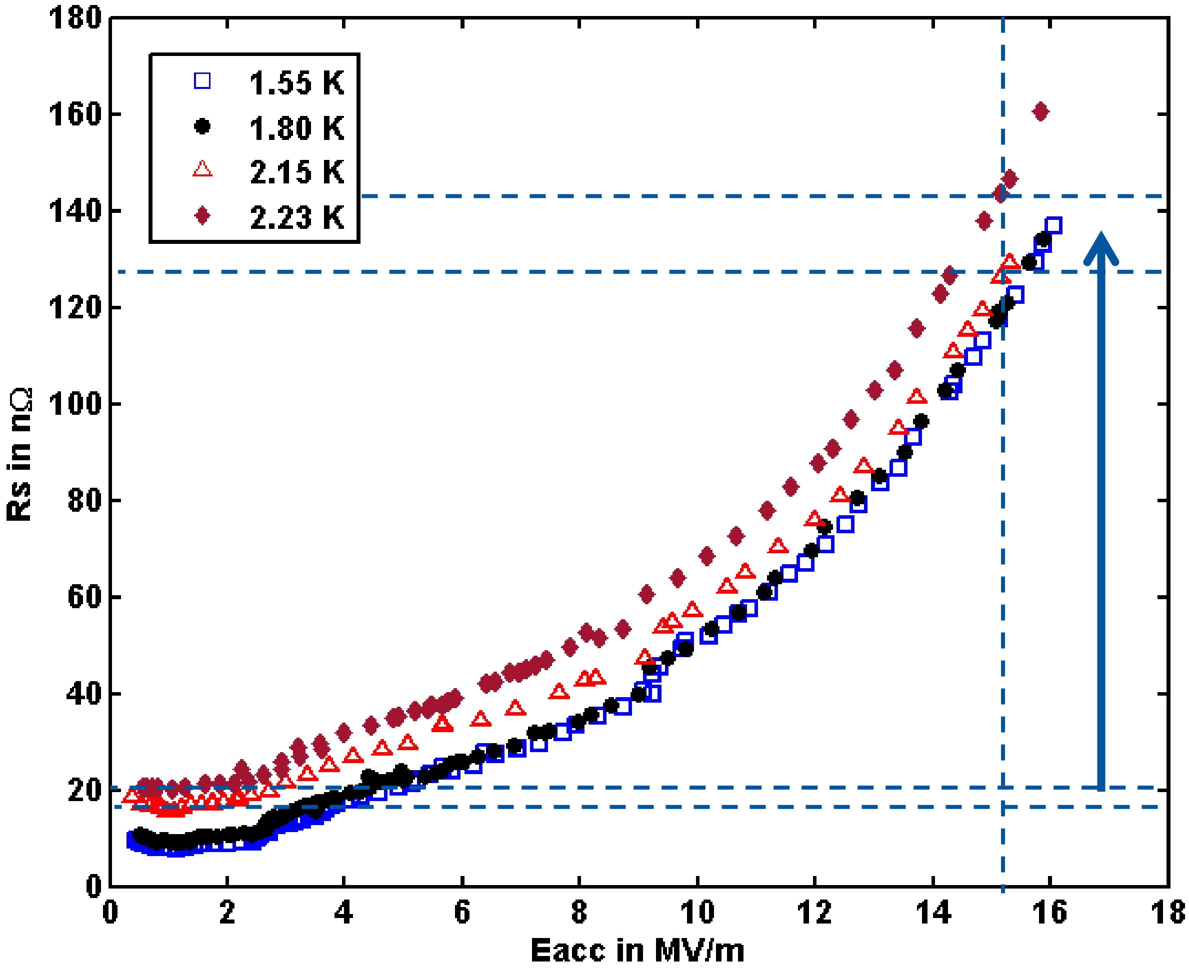
G. Terenziani, S.Calatroni, A. P. Ehiasarian, T. Junginger, S. Aull

HIPIMS on 1.3 GHz Cavity – Deposition System



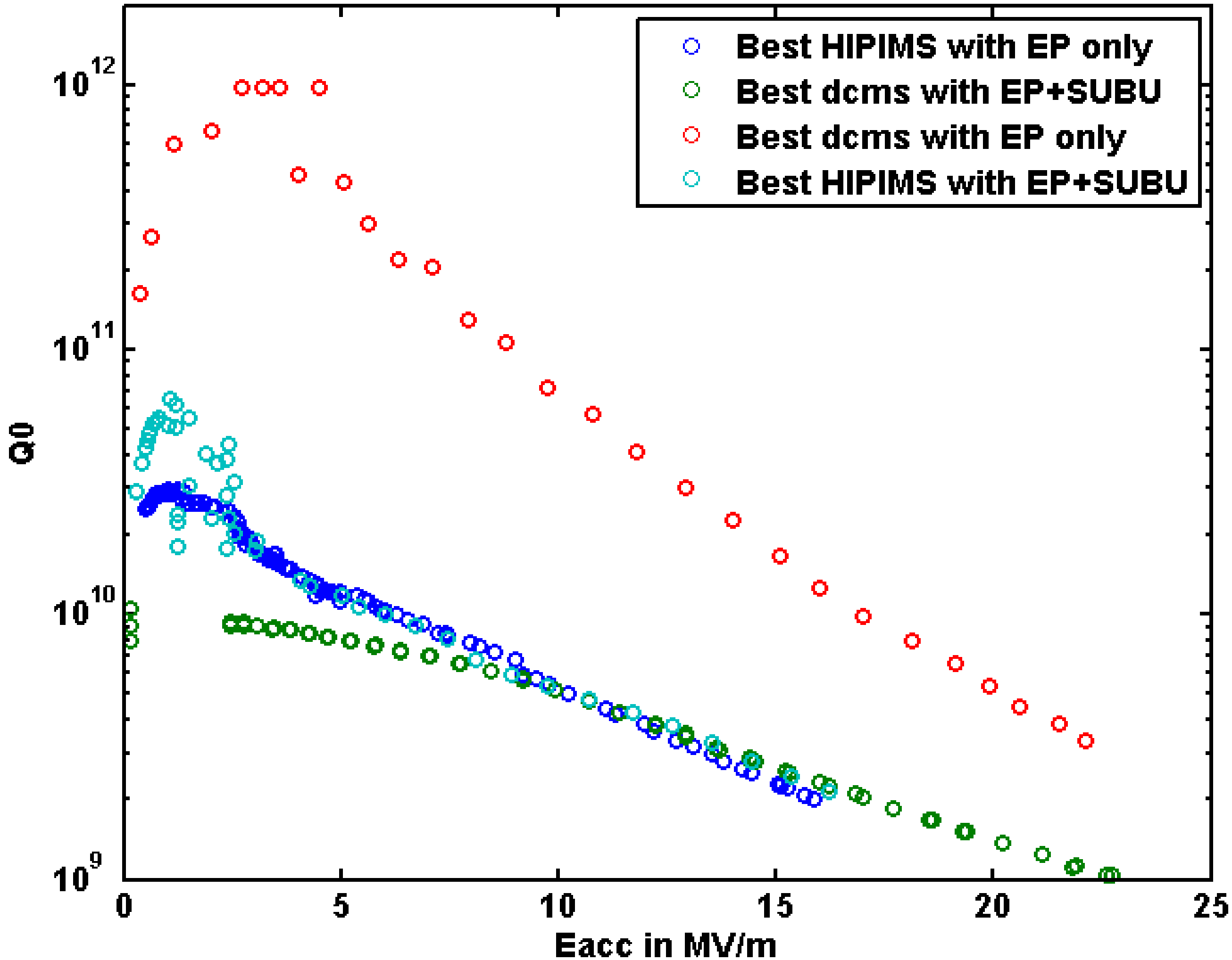


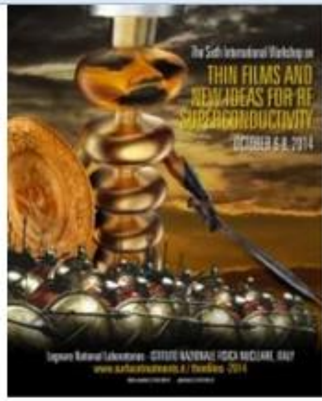
HIPIMS on 1.3 GHz Cavity M2.7 – R_s Vs E_{acc}



There is an increase of about 15 nΩ from low field to 15 MV/m between the curves measured just below and just above λ transition
→ Q-slope is influenced by thermal boundary, but it is not the dominant effect (≈7%)

HIPIMS on 1.3 GHz Cavity - Results





Experimental Results on Thermal Boundary Resistance for Nb and Nb/Cu

Enzo Palmieri[1,2], A.A. Rossi[1], R. Vaglio[3]

[1] Legnaro National Laboratories of the INFN
[2] Università degli Studi di Padova
[3] Università degli Studi di Napoli

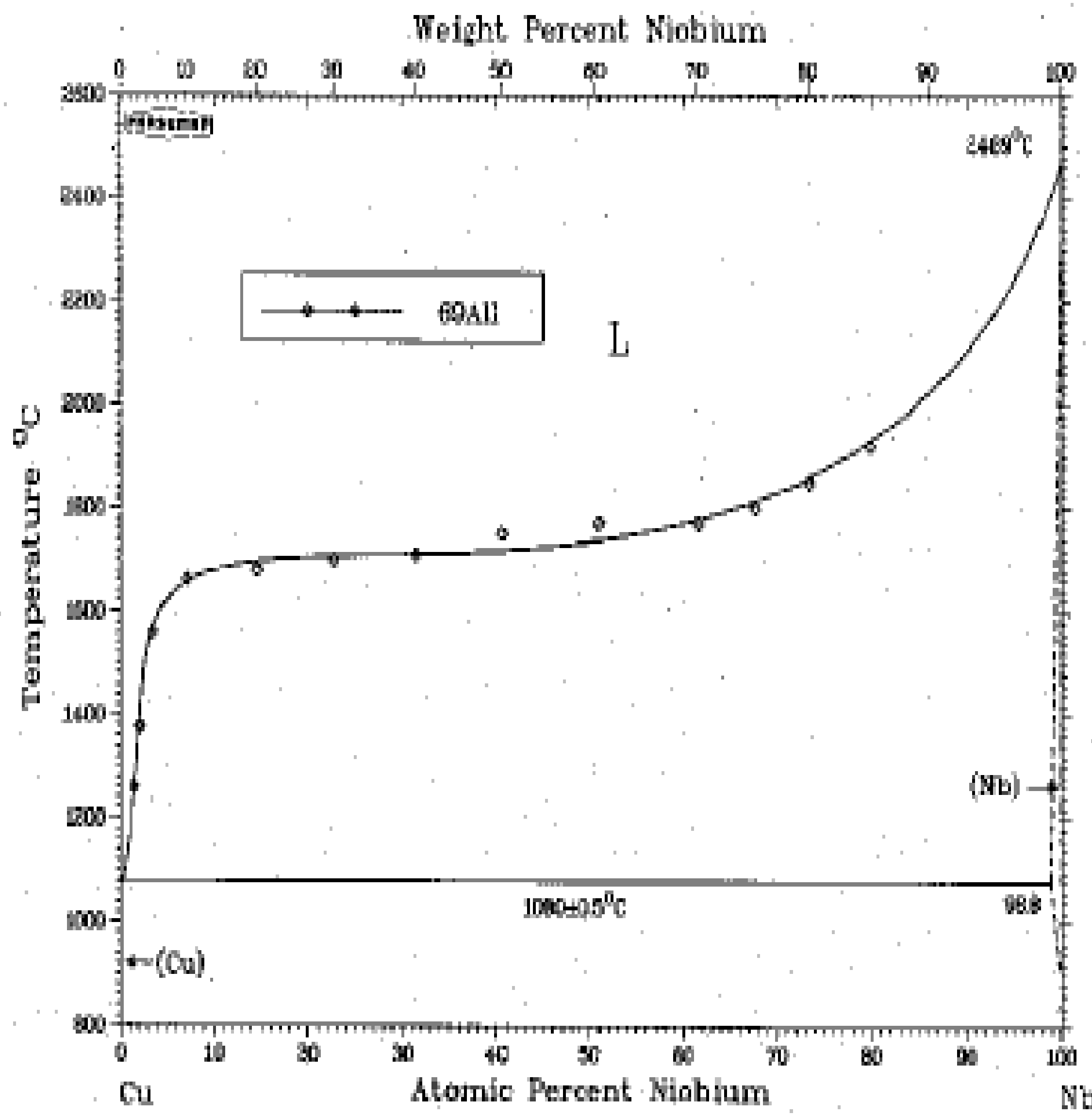
The Cathodic Arc coated cavity deposited by Soltan Institute and INFN- Roma2 was never measured ….

do you know why?

Bad adherence between Cu and Nb is a common problem!

If the adhesion of Niobium to Copper is not good, the cavity will go in thermal runaway!!!!

Fig. 1 Cu-Nb Phase Diagram



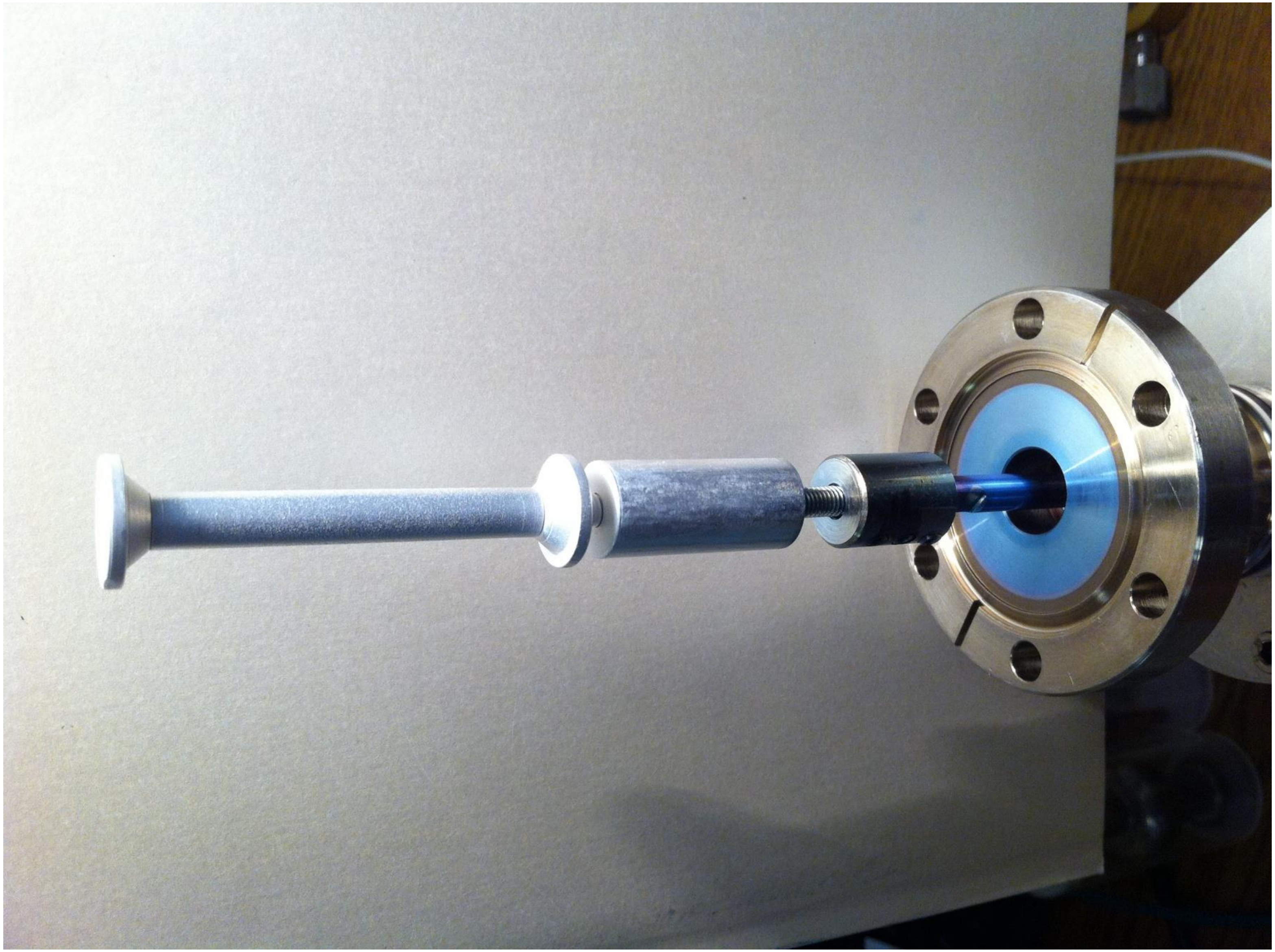
Showing liquidus data of [69All] and 1080 °C isotherm from [79Pet].

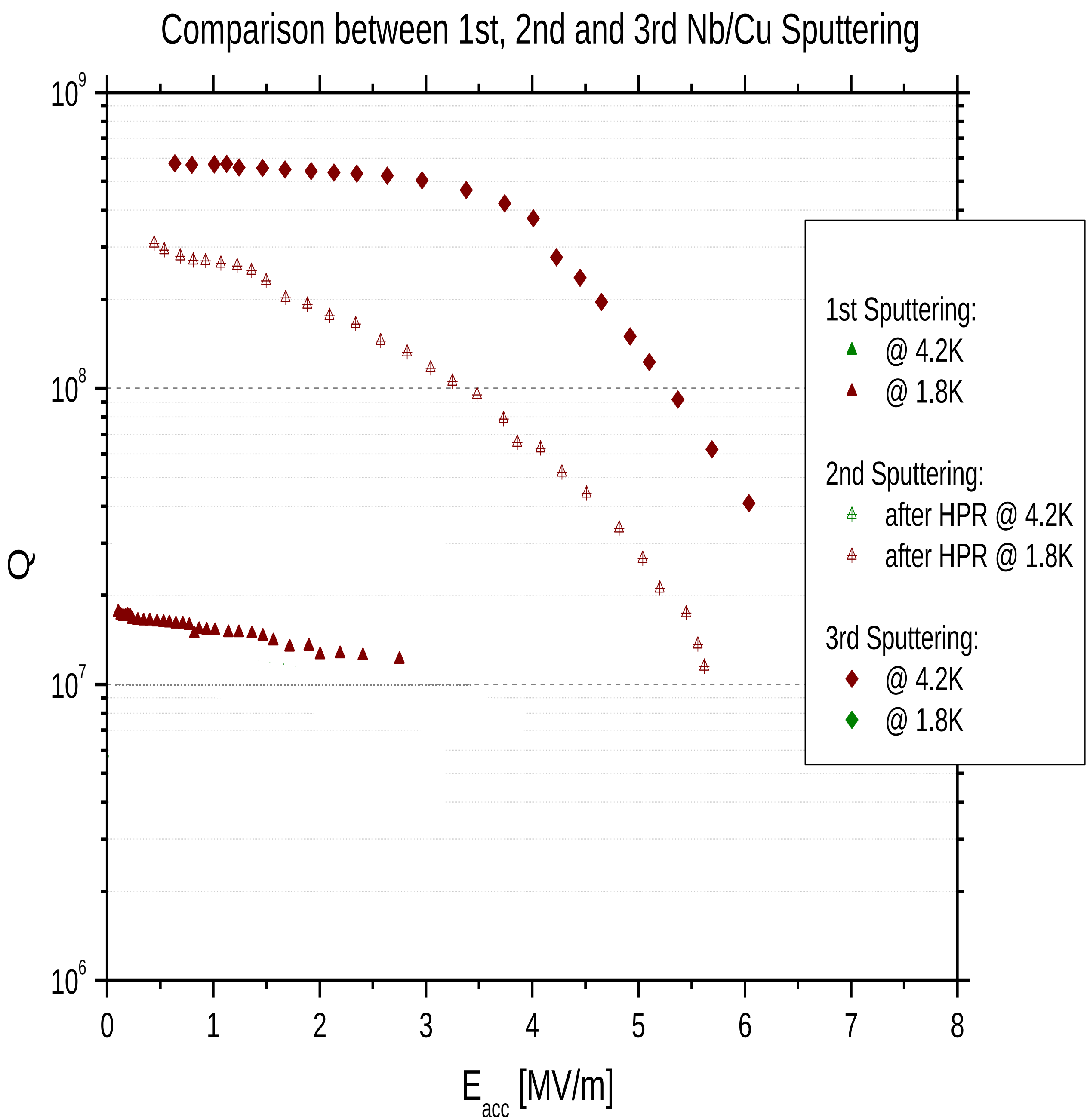
D. J. Chakrabarti and D. E. Laughlin, 1982.

What has high solubility both in Niobium and in Copper?

- Palladium
- Silver
- Tin
- Alluminum

"Silver Cathode"





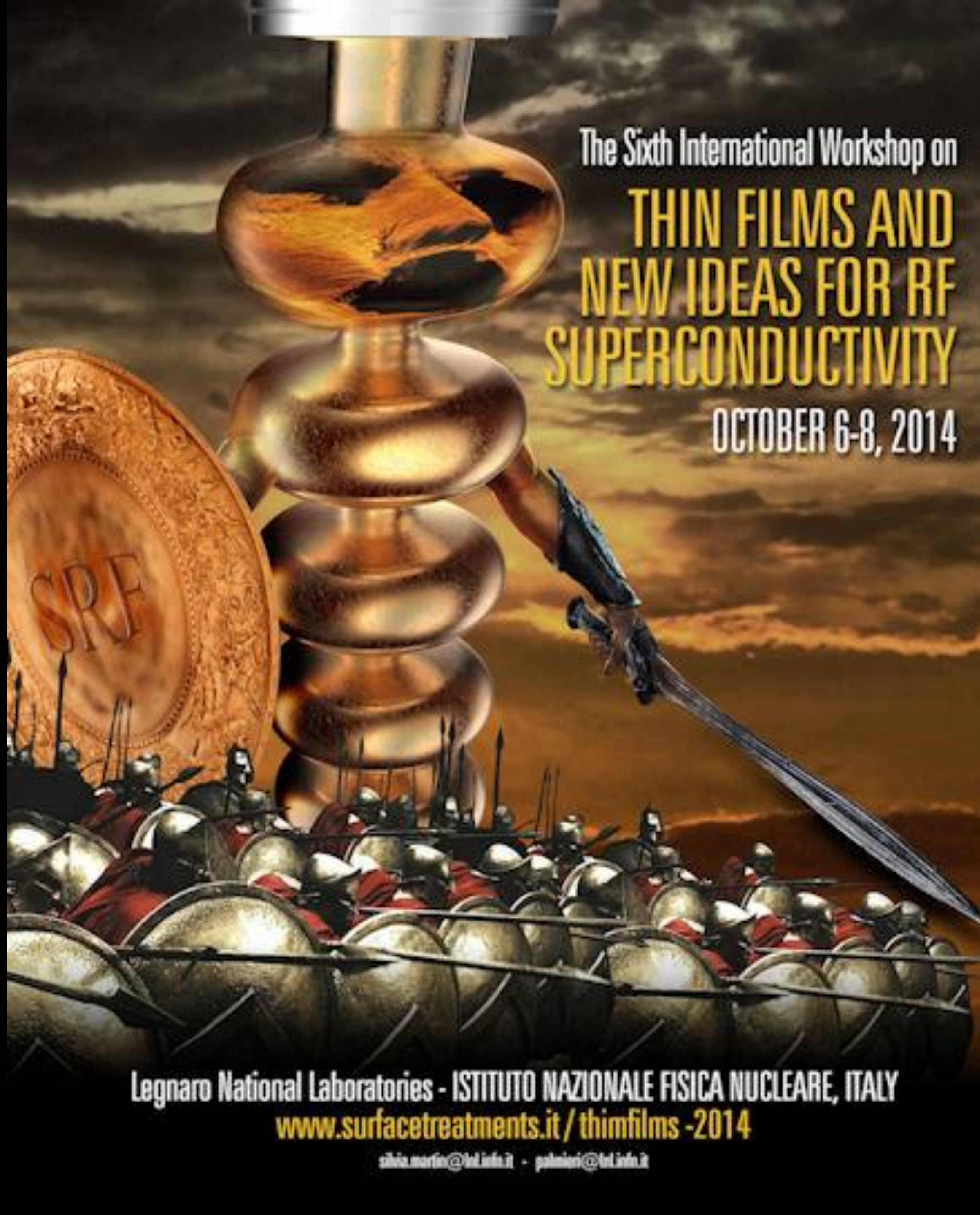
Comparison between 1st, 2nd and 3rd Nb/Cu Sputtering
Q
10^9
10^8
10^7
10^6
0
1
2
3
4
5
6
7
8
E_{acc} [MV/m]
1st Sputtering:
@ 4.2K
@ 1.8K
2nd Sputtering:
after HPR @ 4.2K
after HPR @ 1.8K
3rd Sputtering:
@ 4.2K
@ 1.8K

If we want to improve SRF performances

we must study more deeply Cryogenics

and precisely Heat Transfer mechanism from a Surface to Liquid Helium

If the adhesion of Niobium to Copper is not good, the cavity will go in thermal runaway!!!!


The Sixth International Workshop on
THIN FILMS AND
NEW IDEAS FOR RF
SUPERCONDUCTIVITY
OCTOBER 6-8, 2014
SRF
Legnaro National Laboratories - ISTITUTO NAZIONALE FISICA NUCLEARE, ITALY
www.surfacetreatments.it / thimfilms -2014

9. AoB: Thin film working group proposal (E. Jensen)

CERN would like to perform some thin films R&D related to LHC, FCC, HIE-Isolde. Sarah Auel has started such a working group, outside of TTC, but Erk Jensen proposes to put the activity under the auspices of TTC. The overlap with the thin-films workshop is expected to be complementarity, similar to that of the SRF workshop. Erk notes interest from Americas already (Cornell, JLab), others welcome. Note that thin films in SRF are already quite relevant for the low-beta community.

Decision

The formation of a 'Thin Film' Working Group is approved.

Next steps: Propose to adapt the high Q0 charter, and include the Technical Board in the founding of the working group. CERN to propose a Working Group coordinator.

Participants to Collaboration Board Meeting

Present in person: Sergey Belomestnykh (BNL), Sébastien Bousson (IPN-Orsay), Massamba Diop (Synchrotron SOLEIL), Camille Ginsburg (FNAL, Deputy Chair), Hitoshi Hayano (KEK), Erk Jensen (CERN), Walid Kaabi (LAL), Eiji Kako (KEK, TB Chair), Stefan Lagotzky (Uni. Wuppertal), Bob Laxdal (TRIUMF), Wolf-Dietrich Möller (DESY, TB co-chair), Alex Neumann (HZB, and representing Uni. Rostock), Olivier Napoly (CEA, Chair), Hasan Padamsee (FNAL), Carlo Pagani (INFN Milan), Enzo Palmieri (INFN Legnaro), Charlie Reece (JLab), Marc Ross (SLAC), Grigory Shirkov (JINR), Felix Schlander (Uni. Mainz), Hans Weise (DESY), Mateusz Wiencek (IFJ-PAN), Akira Yamamoto (KEK, Search Committee), Jiyuan Zhai (IHEP)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for Industrial Applications
Registration deadline: 20th January, 2015
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