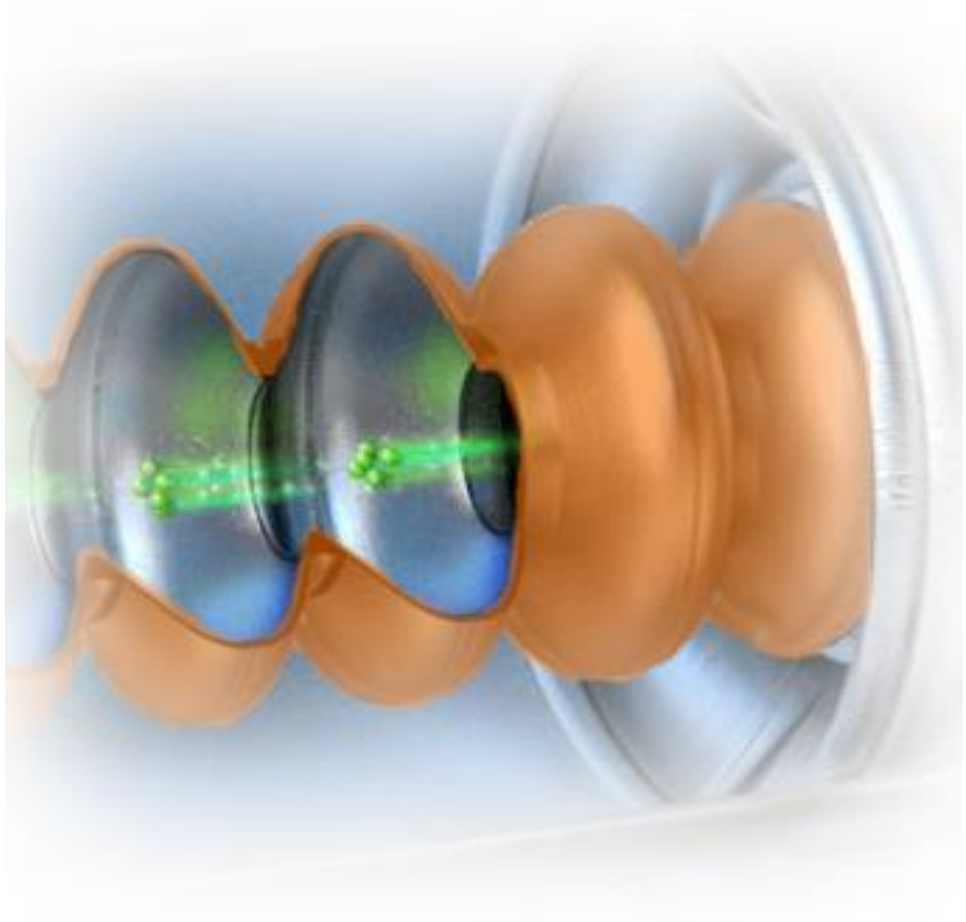
ECR

From samples to cavities

A.-M. Valente-Feliciano



Jefferson Lab

U.S. DEPARTMENT OF ENERGY | Office of Science
JSA

AKNOWLEDGEMENT

Jefferson Lab — D.R. Beverstock, M. Burton, G. Eremeev, F. Marhauser, A. Palczewski, L. Phillips, O. Trofimova, J. Spradlin , C. Reece

irfu cea saclay — C. Antoine, T. Proslier

CERN — M. Arzeo , S. Aull, G. Rosaz

KU LEUVEN — V. Khouzenikov

Norfolk State University — F. Stevie & Group

NSU Norfolk State University — J. Skusa

STFC ASTeC — R. Valizadeh, T. Junginger

Old Dominion University — A. Gurevich

Paul Scherrer Institut PSI — A. Sutter

TRIUMF — R. Laxdal

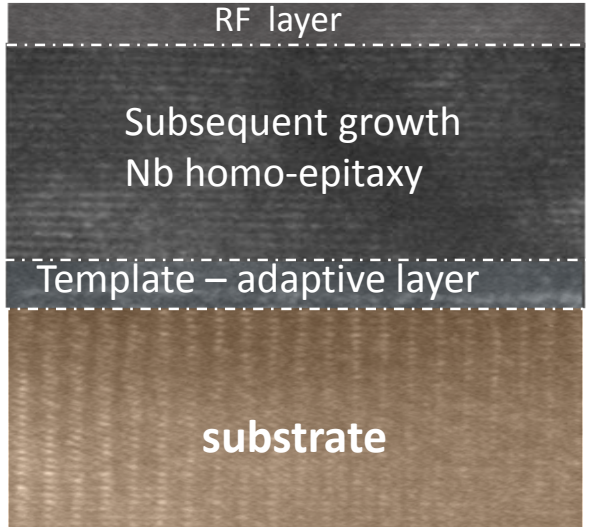
College of William & Mary — Prof. A. Lukaszew & Group, Prof. M. Kelley

Energetic Condensation via ECR

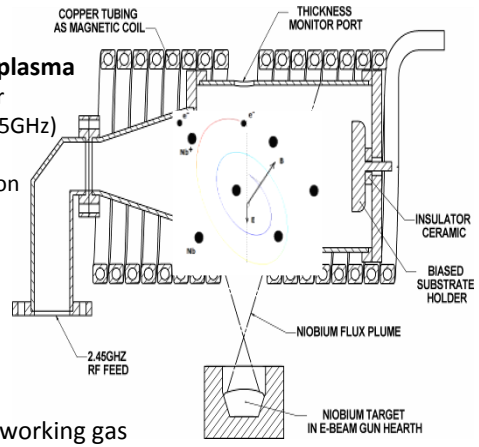
energetic condensation

Sequential phases for film growth

- Interface
- Film nucleation
- Growth of appropriate template for subsequent deposition
- Deposition of final surface optimized for minimum defect density.



Generation of plasma
Neutral Nb vapor
RF power (@ 2.45GHz)
Static B ⊥ E_{RF}
with ECR condition

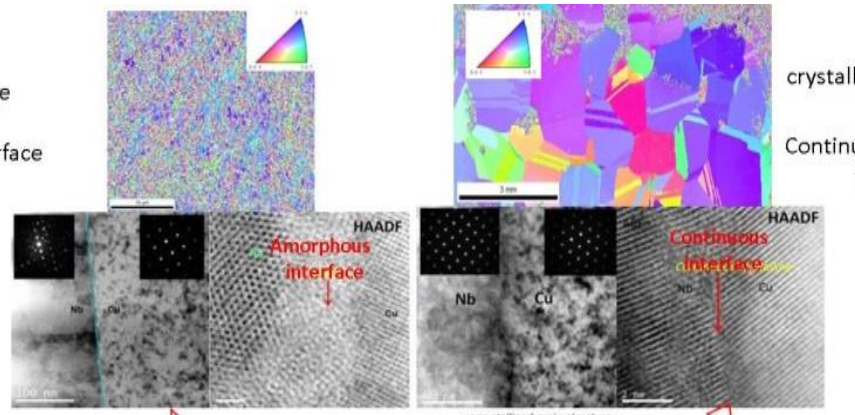


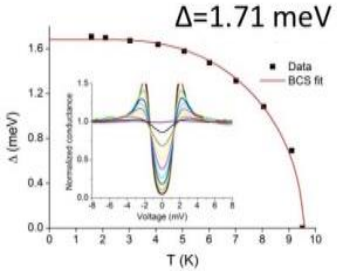
No working gas
Singly charged ions (64eV) produced in vacuum
Controllable deposition energy with Bias voltage
Excellent bonding , No macro particles

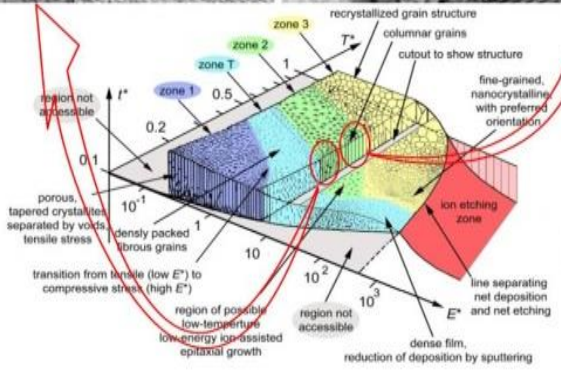
Control over nucleation & subsequent growth, thus structure

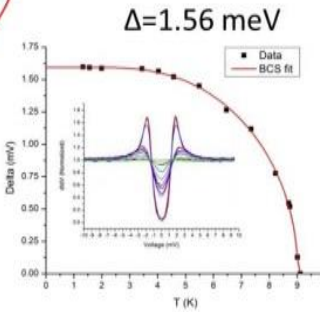
Nb on
native Cu oxide
(200 °C)
Amorphous interface

Nb on
crystalline Cu substrate
(200 °C)
Continuous crystalline interface







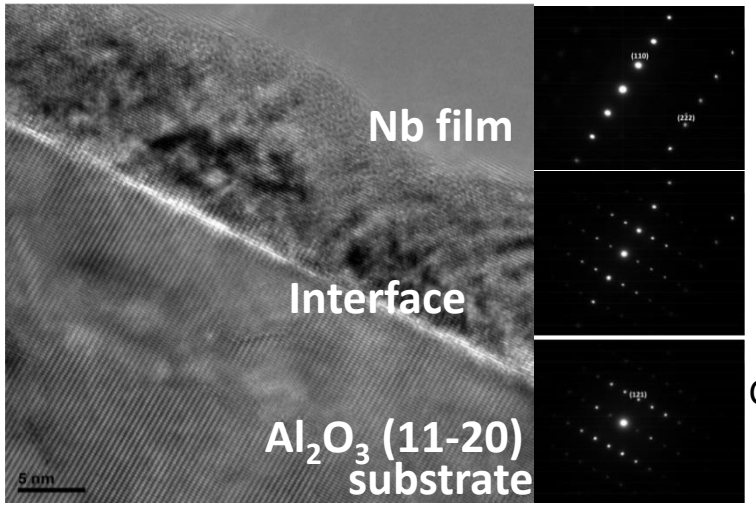


Full control over final SRF performance with strict process protocols

Control over thin film structure, quality (RRR values) , properties, impurity (H) content, adhesion to the substrate

Jefferson Lab

Potential for EC Nb films – ideal case

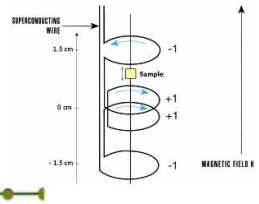


Heteroepitaxy

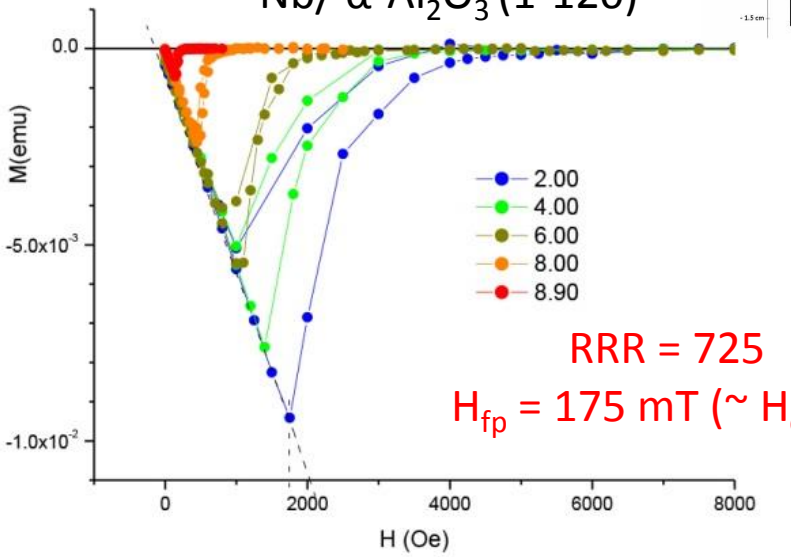
continuously crystalline interface

Crystalline Al_2O_3 (11-20) substrate

dual energy and thick films (interrupted growth)

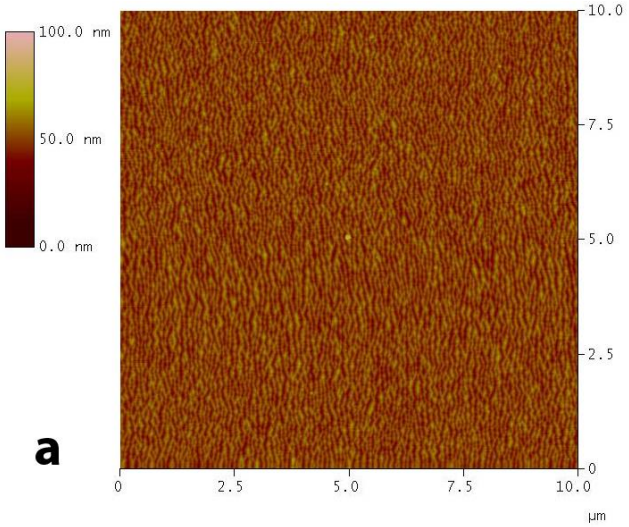


Nb/ α-Al_2O_3 (1-120)

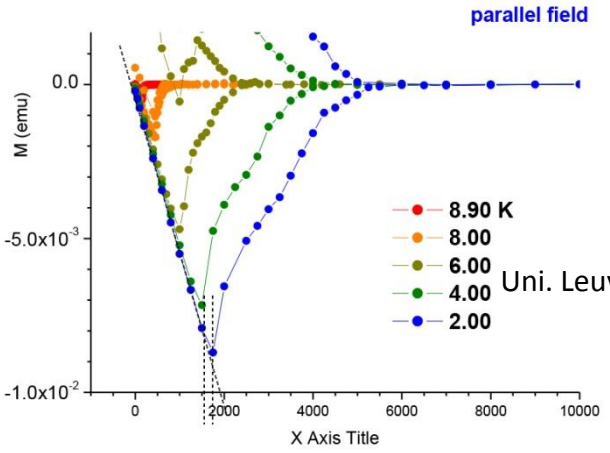


RRR = 725

H_{fp} = 175 mT (~ H_{c1}^{Nb})



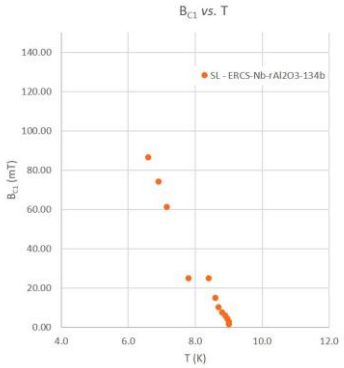
Nb/ α-Al_2O_3 (11-20)

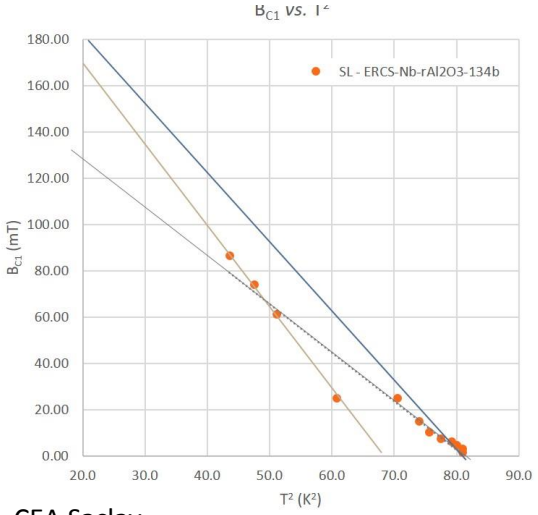


RRR = 489

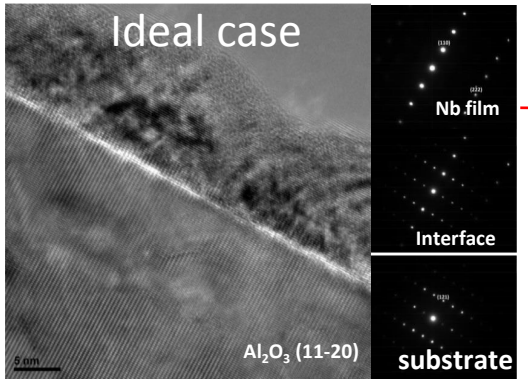
H_{fp} = 155 mT

Local magnetometry

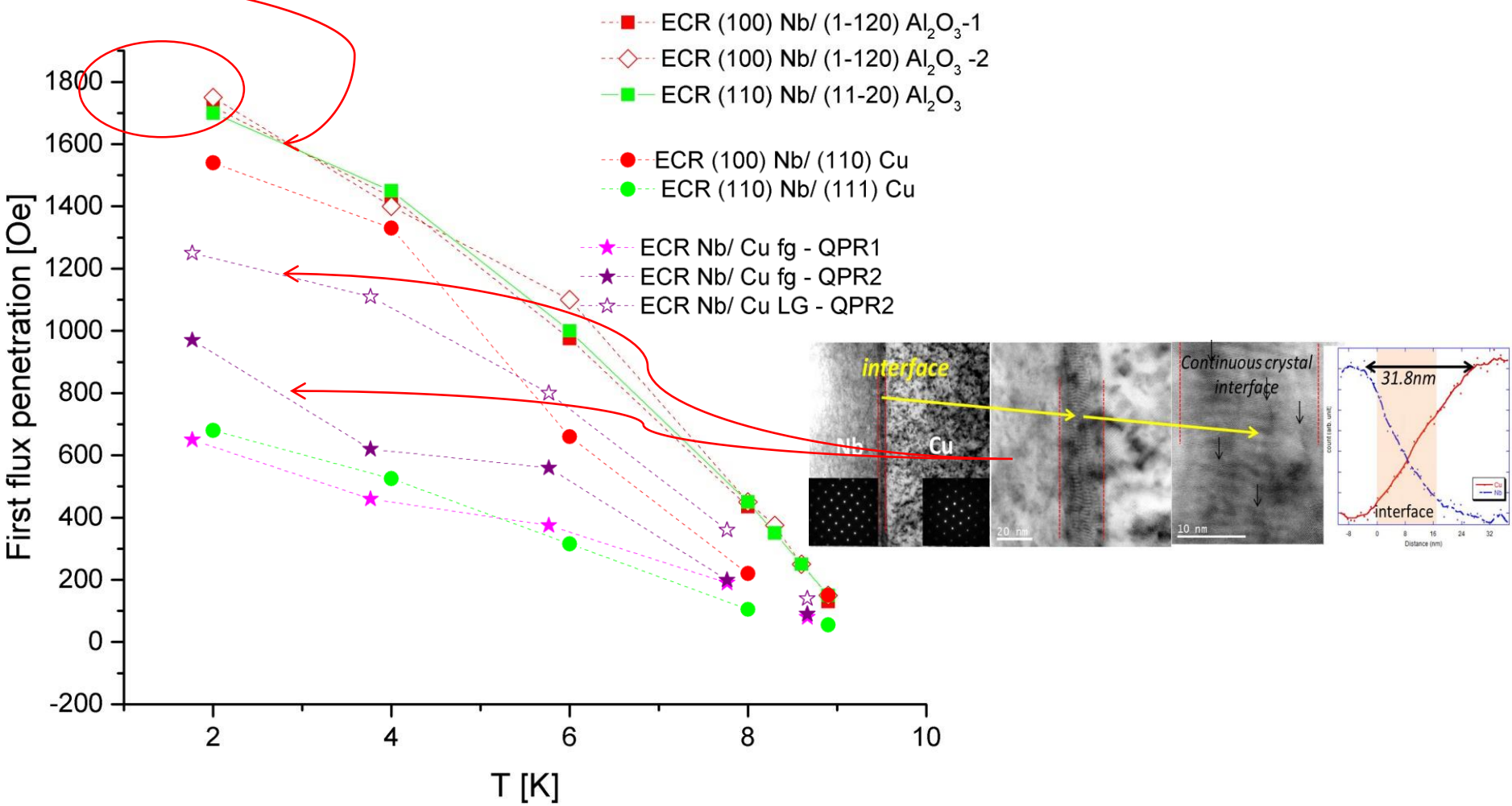




Potential for EC Nb films – real case



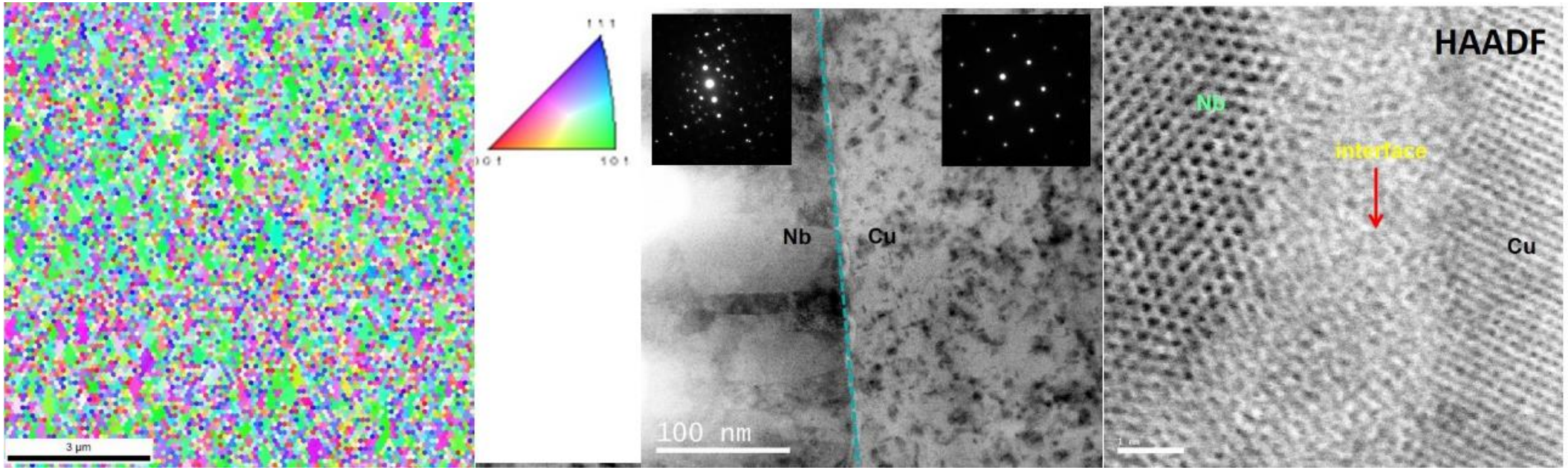
1st Flux Penetration by SQUID



Jefferson Lab

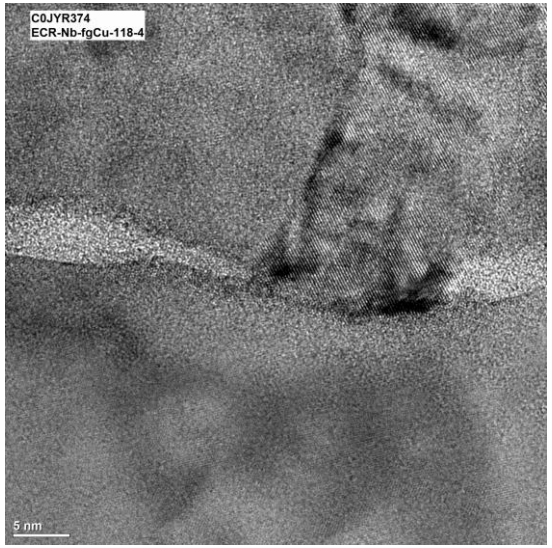
ECR Nb/CuO nucleated at 184 eV – fiber growth

Nb on Cu oxide (200 °C) Amorphous interface

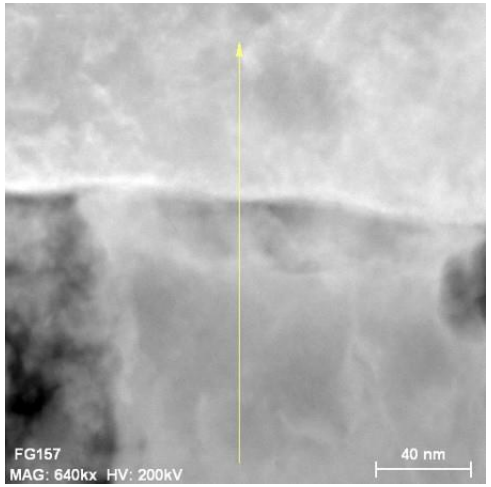


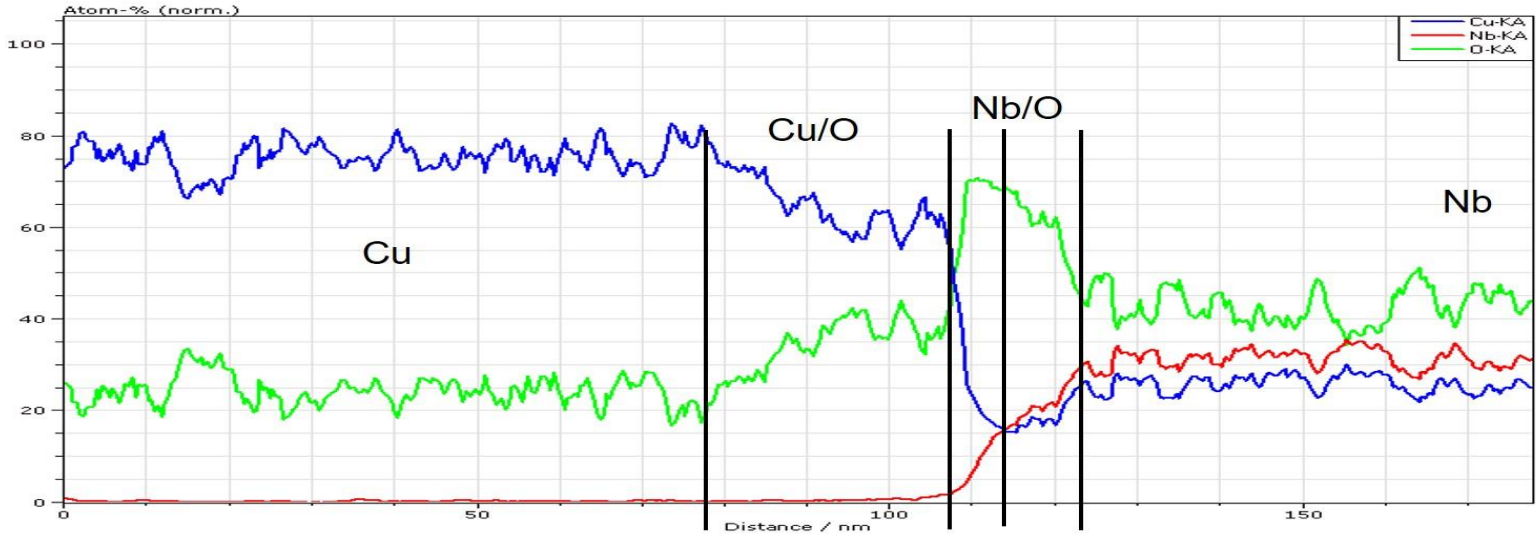
Nucleation @ 184 eV
Subsequent growth @ 64 eV
Baking 200 °C
Coating 200 °C

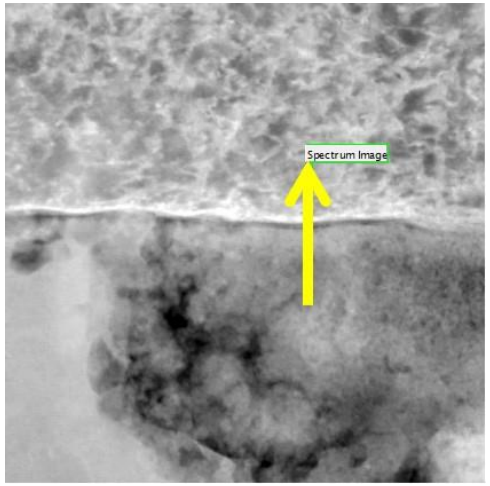
BF TEM image

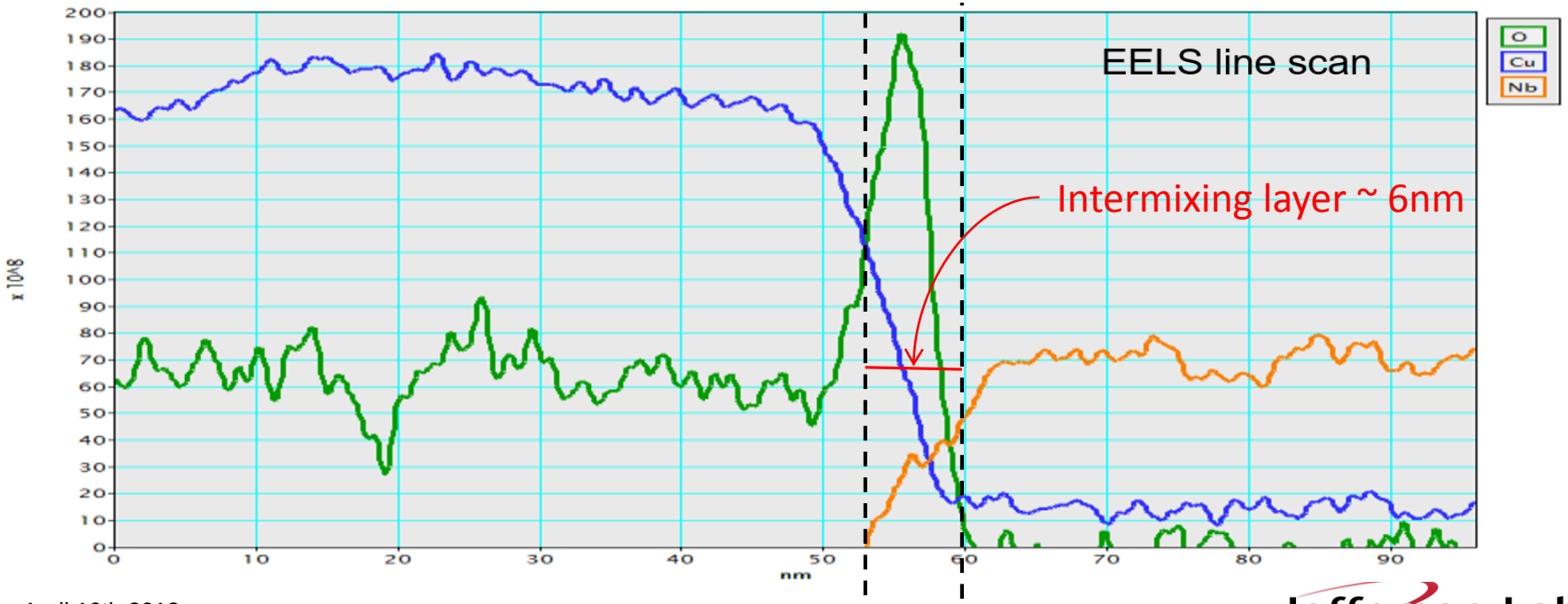


ECR Nb/CuO nucleated at 184 eV– fiber growth



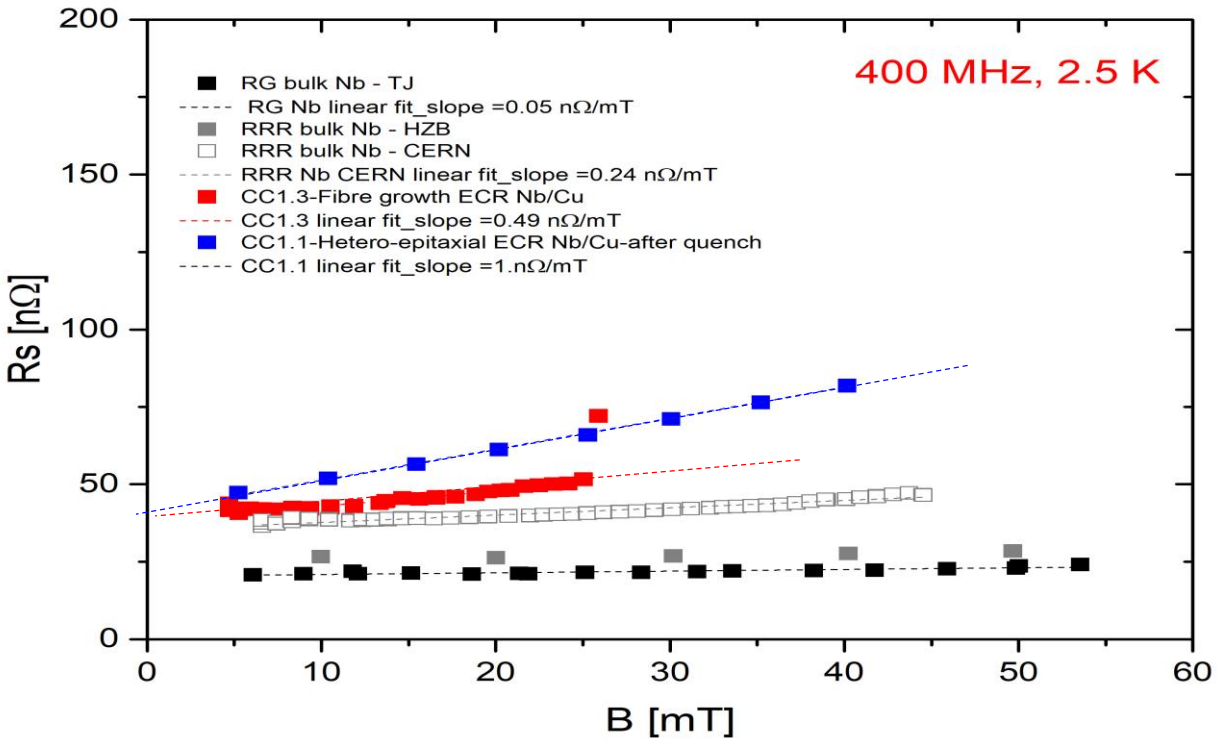


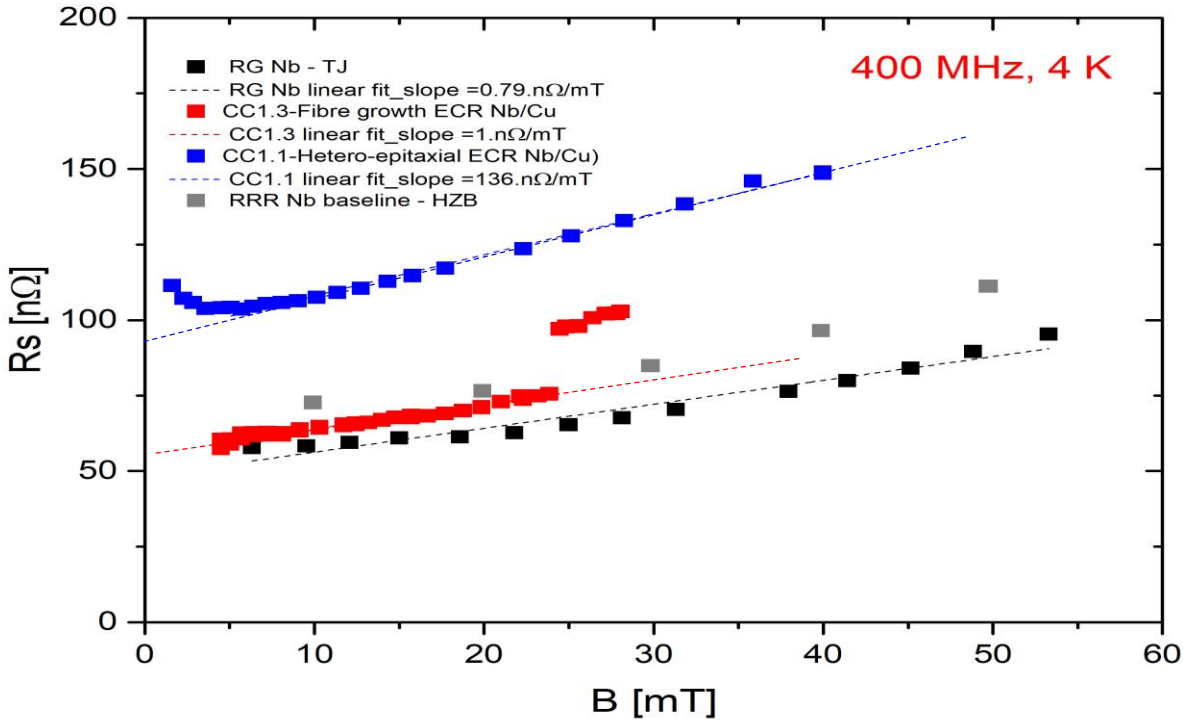


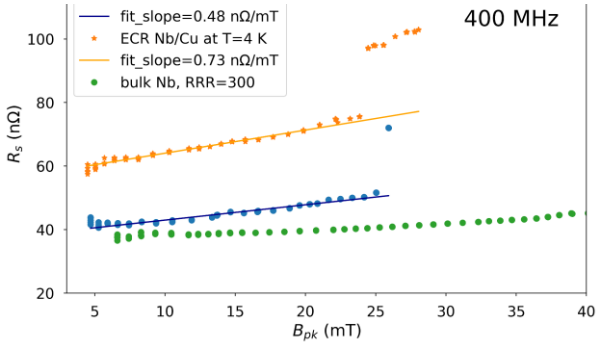


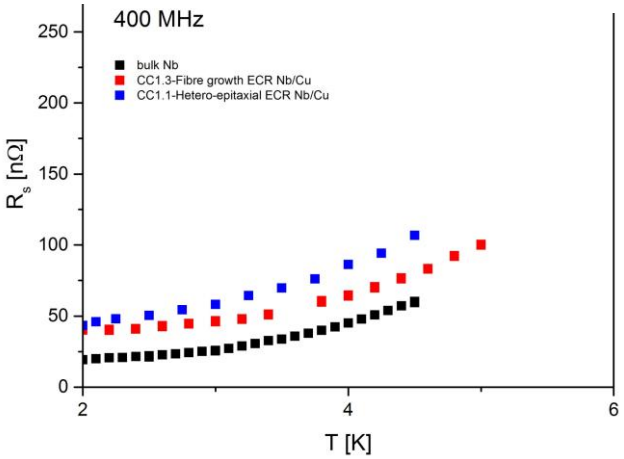
Jefferson Lab

ECR fiber growth Nb/CuO @ 400 MHz

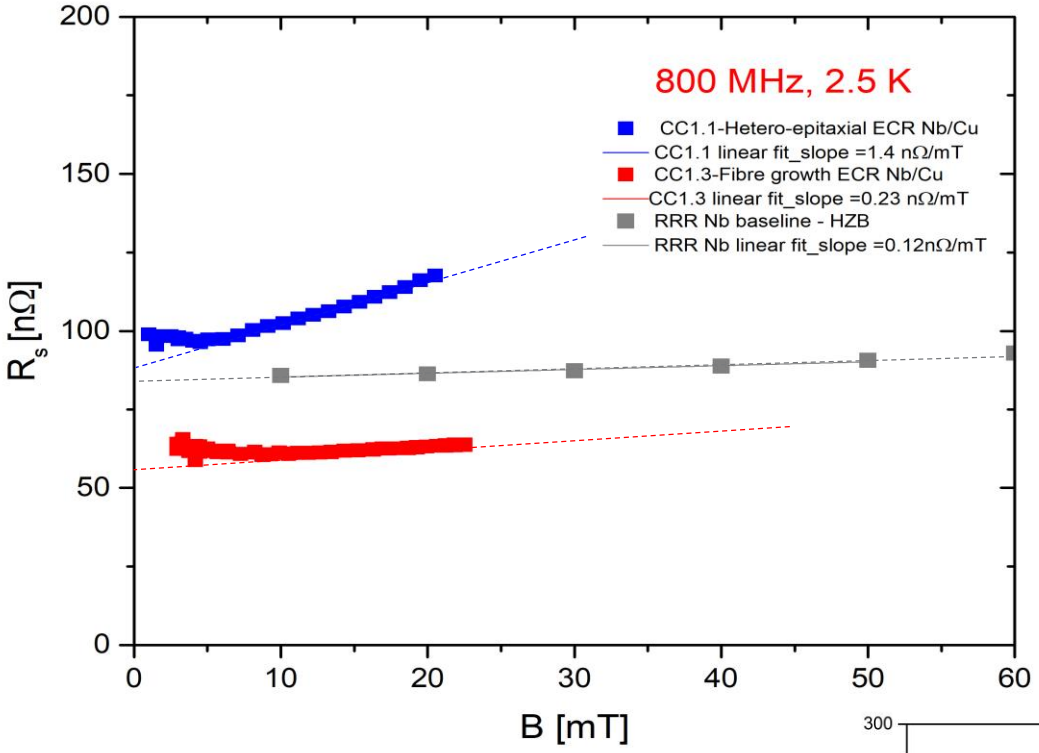


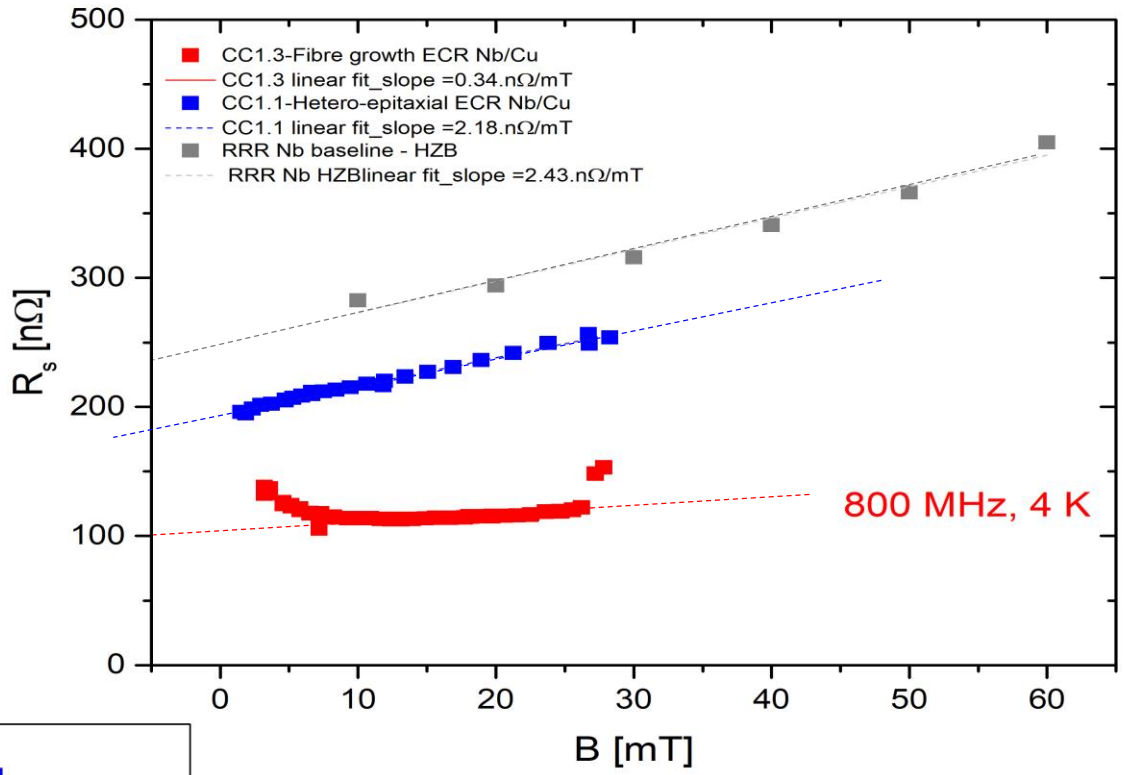


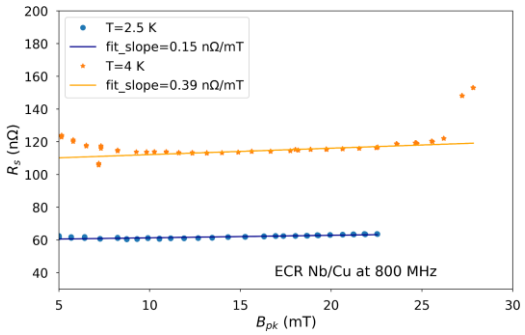


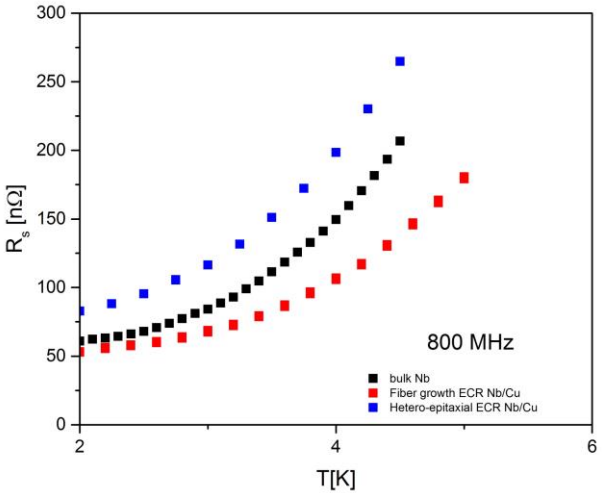


ECR fiber growth Nb/CuO @ 800 MHz









Thermal cycling & trapped flux considerations

M. Arzeo, 14:10 - 14:30, P4 Berlage zaal, 1.9

Quadrupole resonators characterization

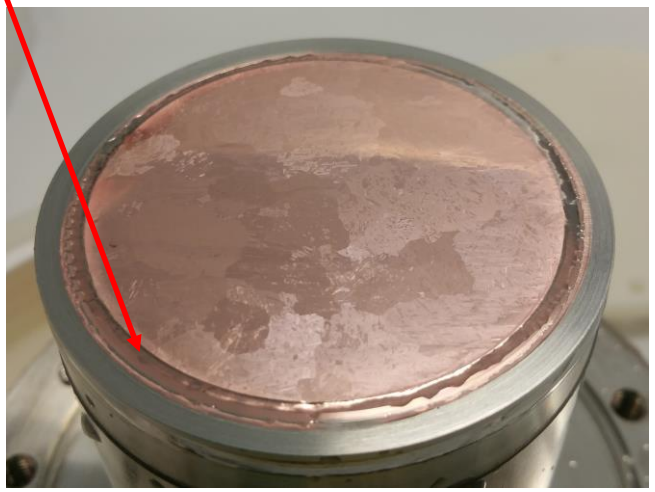
https://indico.cern.ch/event/656491/contributions/2932254/

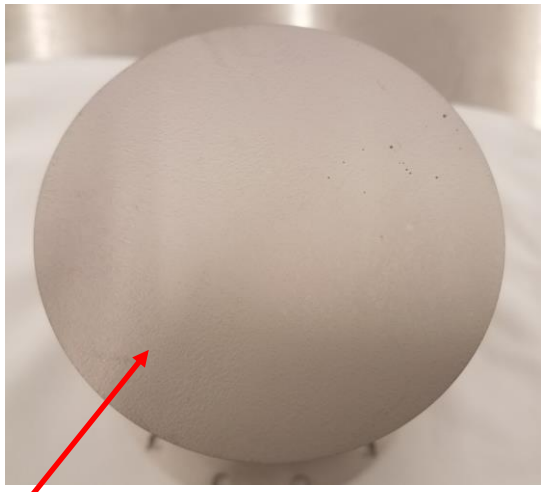
Other considerations

- Resistances still high in QPR RF measurement, bulk & films confounded
- Sample issues?
- Is the weld on top of the sample affecting substrate material, thus growth, thus limiting performance?

Nb/Nb weld

Cu/Nb "weld"



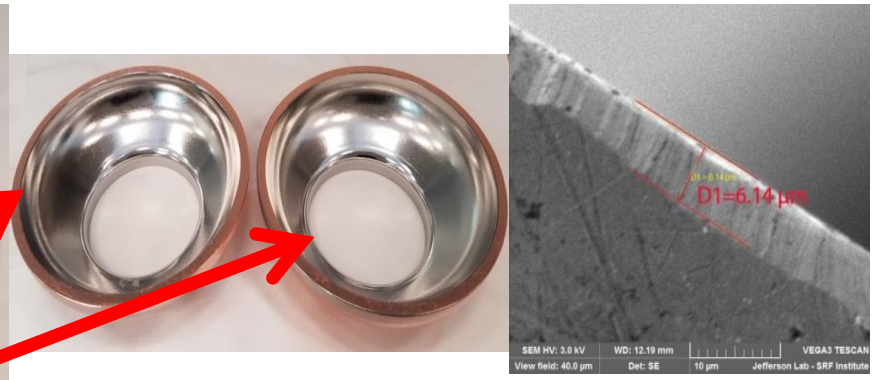


Best samples measured had no weld on the top surface

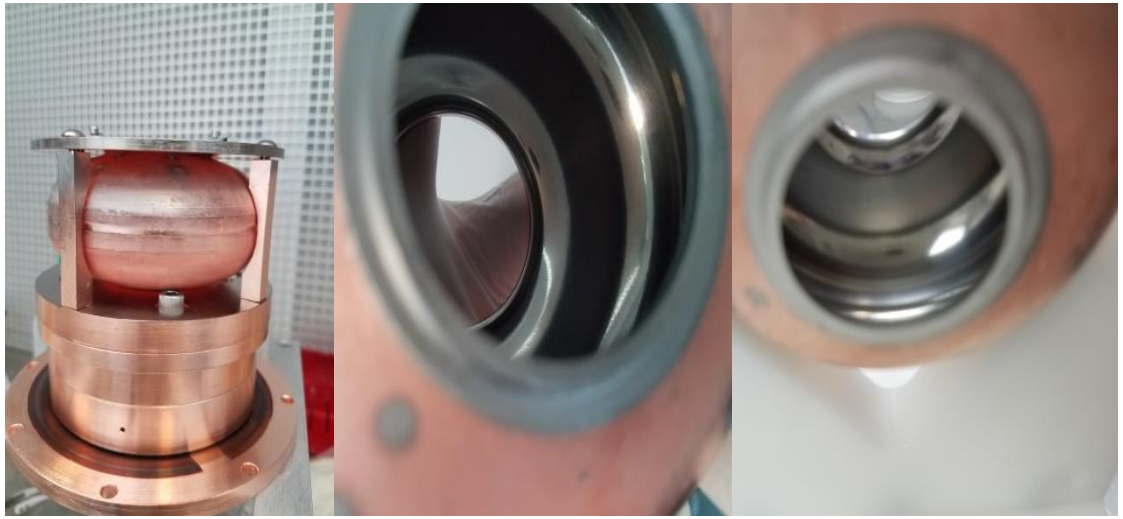
Towards ECR cavity coating

3.75” Tube

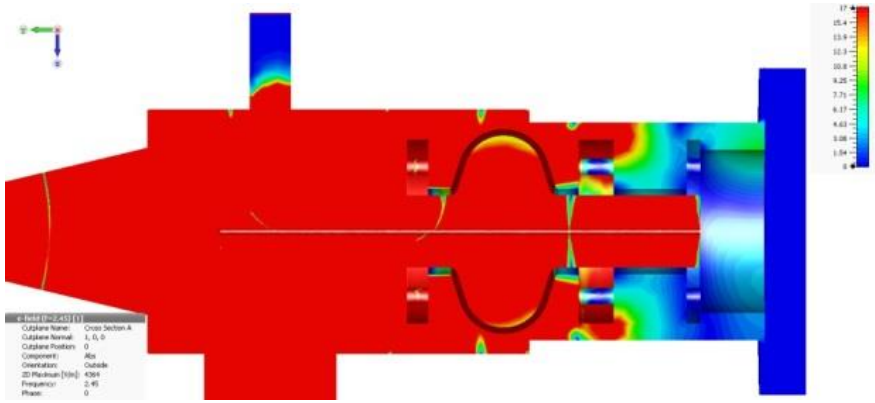
3.9 GHz half cells



3 GHz half cells diffusion bonded & fully coated in-situ



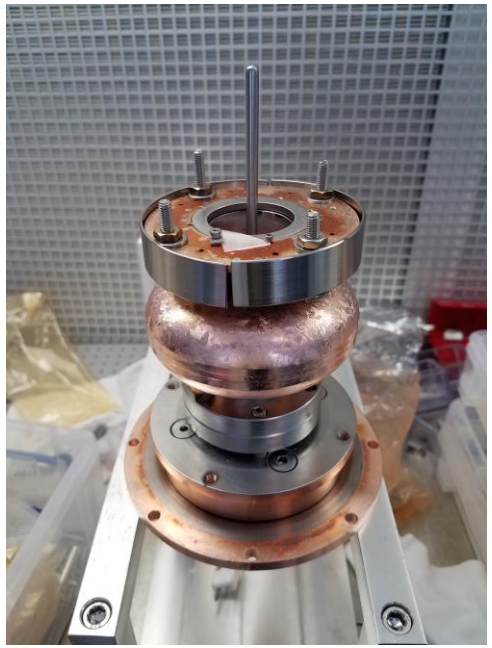
3 GHz Cavity with beam tubes: 5GHz frequency cut-off
Adjust coating geometry to allow RF fields to penetrate the cell and get adequate plasma conditions

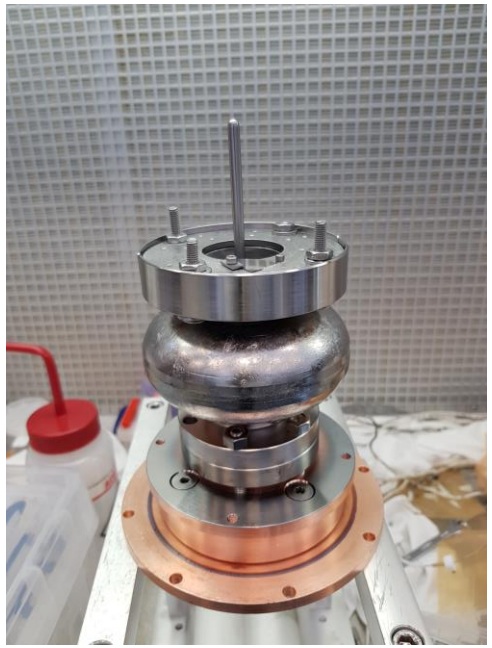


RF and plasma simulations ongoing
with Comsol Multiphysics, PIC-MC soon

Towards ECR cavity coating

Coating in 2 steps , with dry N_2/O_2 exposure in between



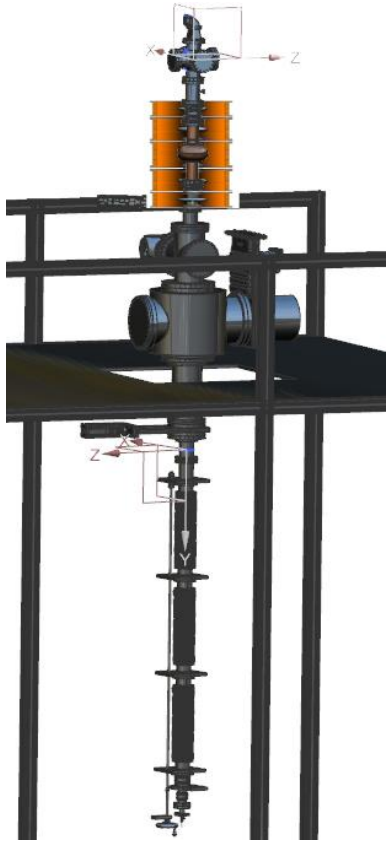


Truncated 3 GHz with
Beam tube extensions
Awaiting RF test

Development of Nb Thin Film Cavity Deposition

ECR cavity deposition system design

Up to 400 MHz, for elliptical and more complex geometries



HIPIMS

M. Burton, L. Phillips, et. al.

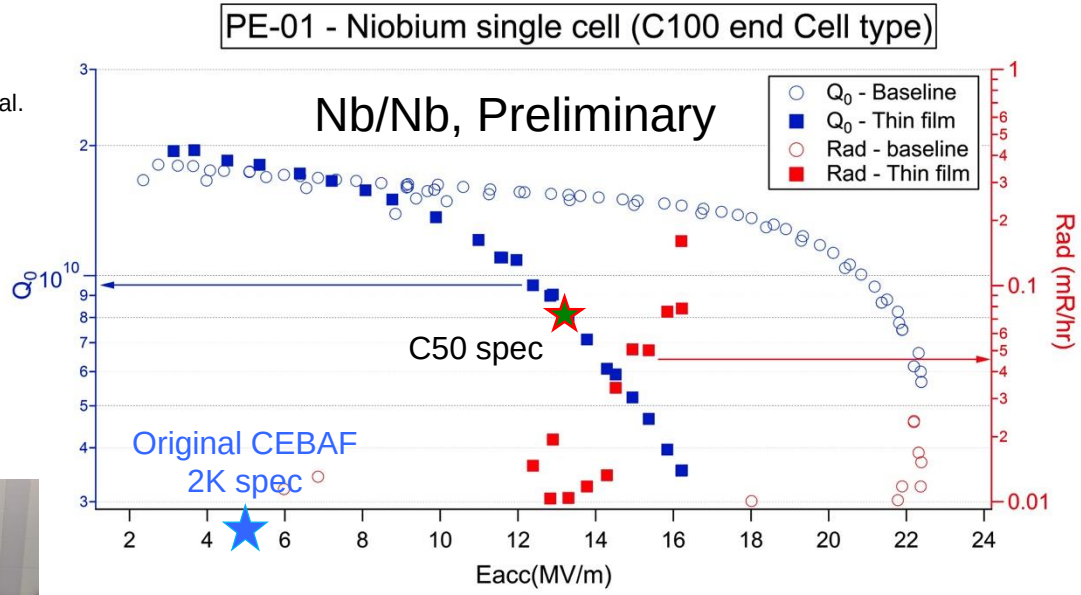
Upgraded Deposition System

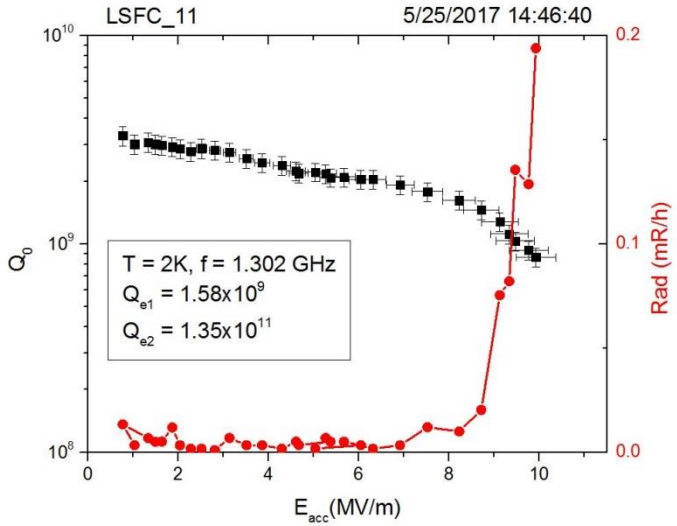
- Tripled Pulse Power Capability
- Permanent Vertical System Operation
- Very low surface roughness
- Hetero-epitaxial Growth
- First cavity coating tests encouraging!

Vertical coating system

1.3 GHz Nb/Cu cavity

HIPIMS discharge



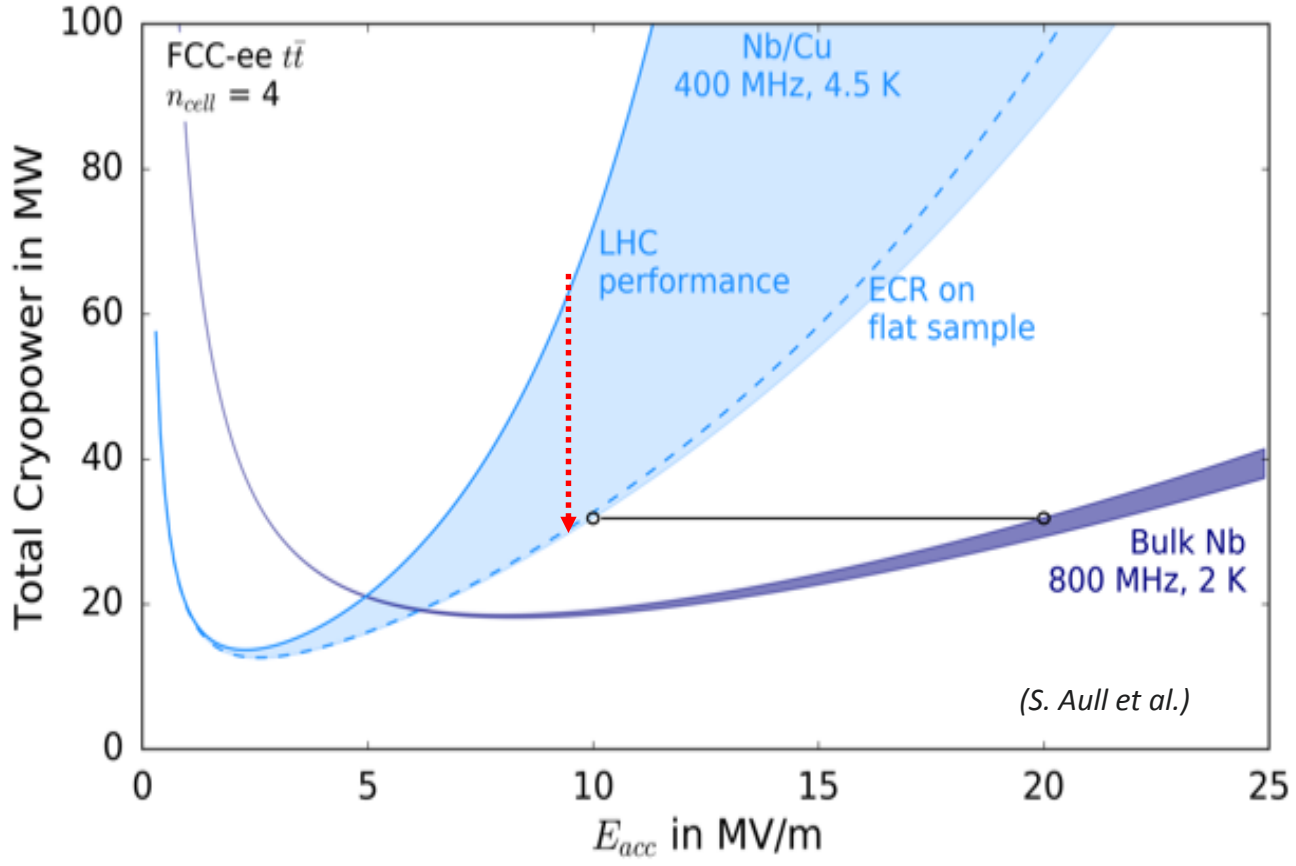


Jefferson Lab

CONCLUSION

- Mitigation of Q-slope confirmed for both epitaxial and fiber growth ECR films
- Fiber growth films thus far seem better performing than hetero-epitaxial films (parallel with DC magnetron sputtering studies?)
- Need more RF measurements statistics
- ECR show promising SRF results with unprecedented thin film material properties, considerably improved compared to the state-of-the-art.
- Energetic condensation techniques are a reasonable stepping stone to truly “engineered SRF Nb surface”
- Development of 3 GHz coating in sample system still on going
- Concept and design in place for an ECR cavity coating system (requires funding)

Perspectives for SRF Nb Thin Film Cavity



The perspective of cavity performances based on ECR sample RF behavior yields similar cryogenic losses for Nb/Cu at 400 MHz and 4.5 K and bulk Nb at 800 MHz and 2.0 K.

- **Basic material processes exist**
  - proof-of-principle demonstrations for modest field applications
- **Principal challenges at present**
  - Establish adequate process controls
  - Address technical challenges with scale-up

- **Tool-up for big cavities & refine process parameters in parallel on smaller scales.**
  - Done right, reasonable stepping stone to truly "engineered surface", with all the benefits of high Q, high field, low cost, high reliability systems.

DANK JE

THANK YOU

ECR Nb/Cu large grain– Surface resistance via QPR

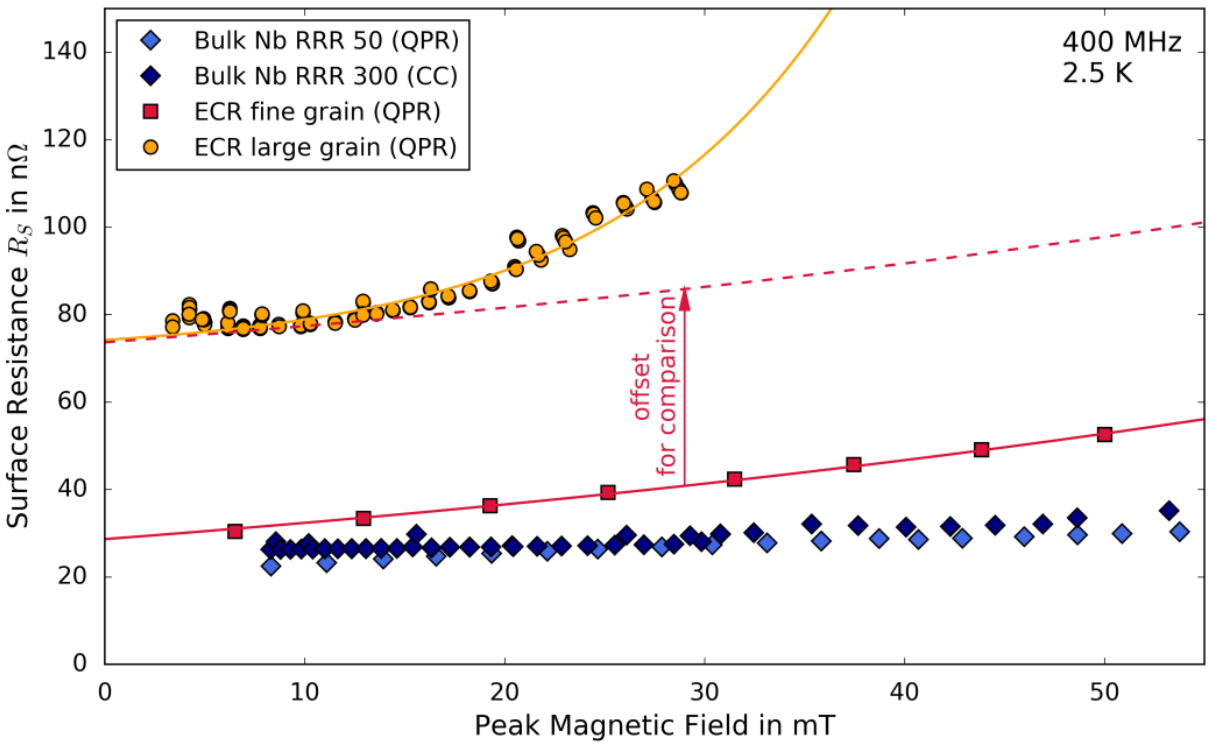
Hetero-epitaxial film Nb on large grain OFHC Cu, 360 °C bake & coating
184 eV for nucleation/early growth + 64 eV for subsequent growth

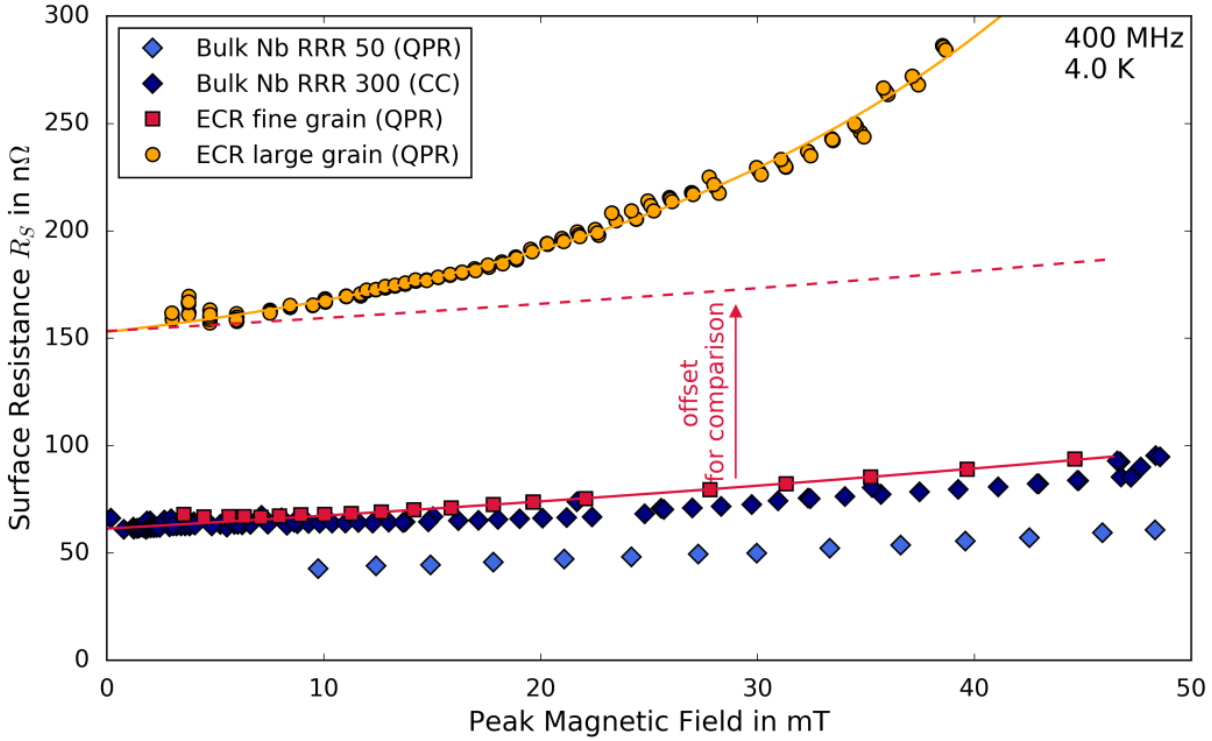
S. Aull, CERN

ℓ* [nm]	RRR
358 ±1	133 ± 21

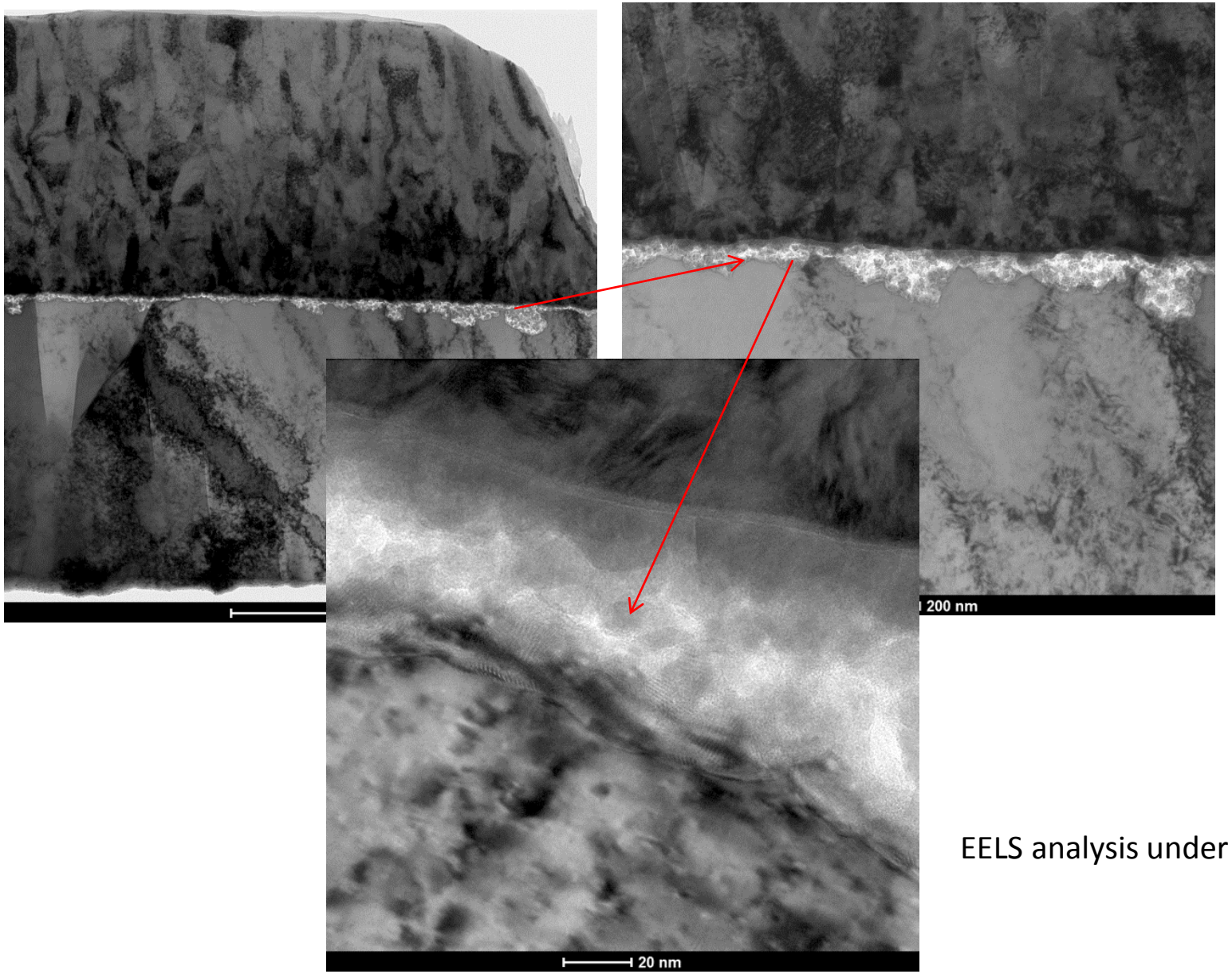
* with λ_L = 32 nm **T_c= 9.42 ± 0.12 K**

	R_{res} [nΩ]	λ(0K) [nm]
400 MHz	94± 3	40 ± 2
800 MHz	158 ± 14	38 ± 1
1200 MHz	375 ± 12	38 ± 1





ECR Nb/Cu large grain– Surface resistance via QPR



EELS analysis under way