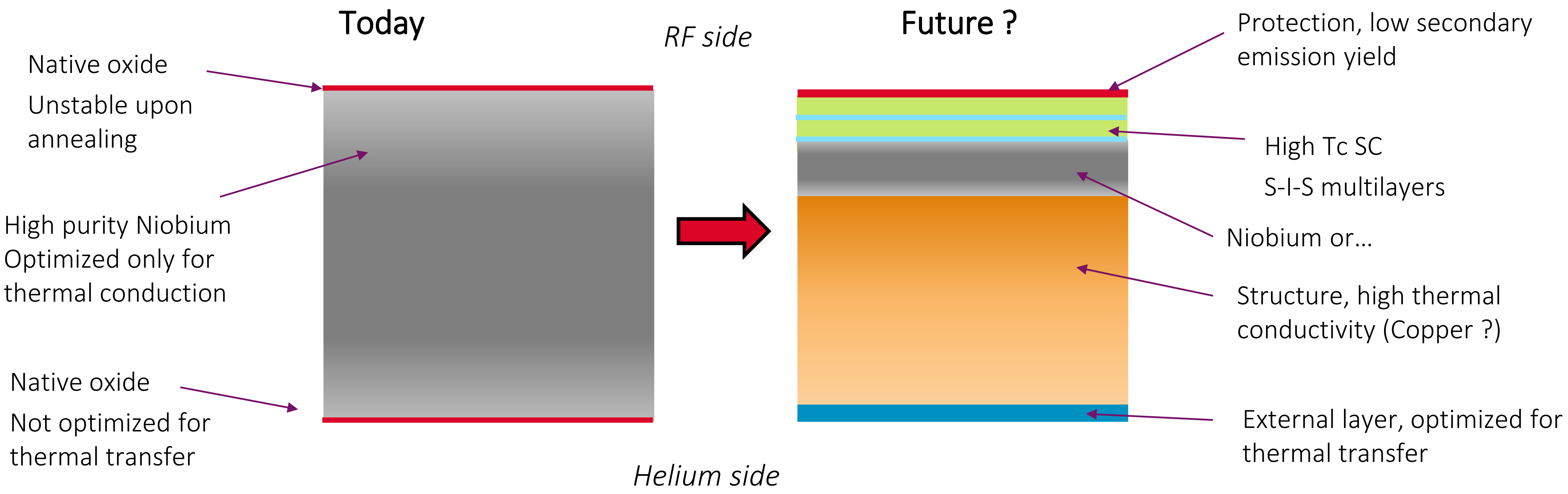
1st I.FAST Annual Meeting Mai 4-6

Oleg B. Malyshev (UKRI) / Claire Antoine (CEA)
WP9 coordinators

Desired: Tailored material for RF cavities



At stakes : COST REDUCTION !!!

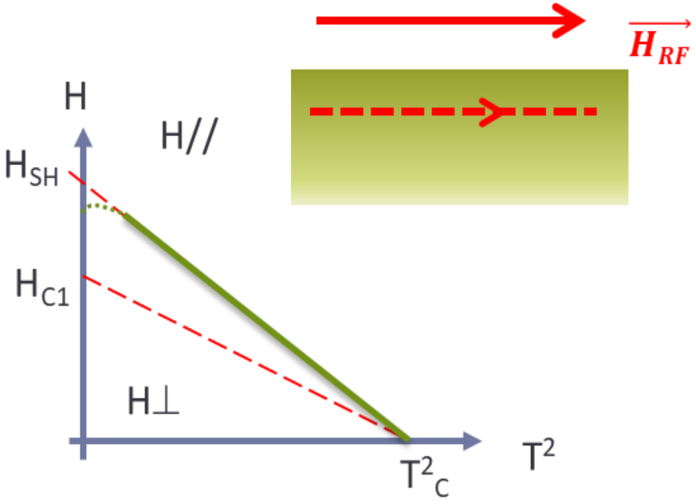
- **Cooling power (any application); can we go to cryocooling ?**
- **High accelerating fields; shorter machines ?**

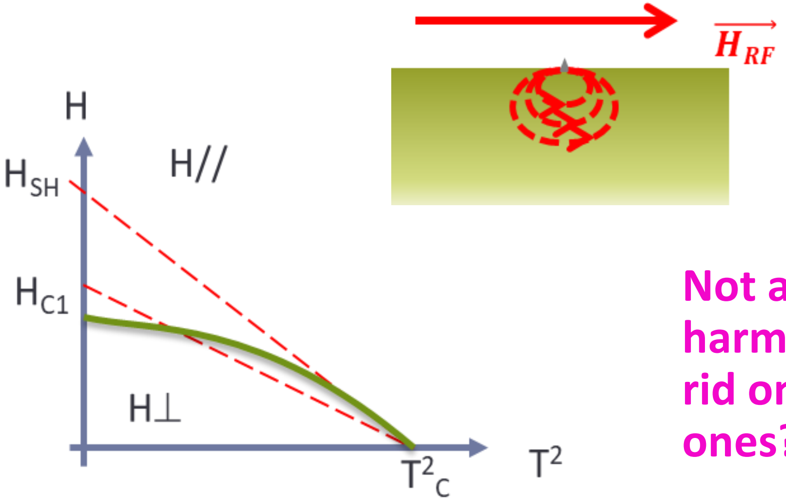
Today's technological limitation

- **Lower dissipation (high Q0) => goes w. higher Tc**
- **Shorter machine (high Eacc=> goes with higher transition field (H_{SH} or H_{C1} ?)**

Physics vs Real life : today we are limited by defects

SRF: no vortex (flux line) inside SC



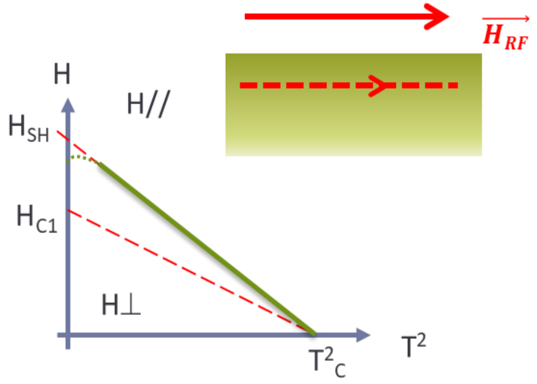


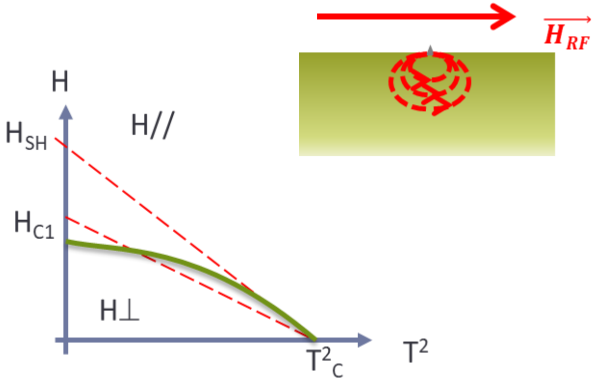
Not all defect are harmfull, how to get rid only of the bad ones?

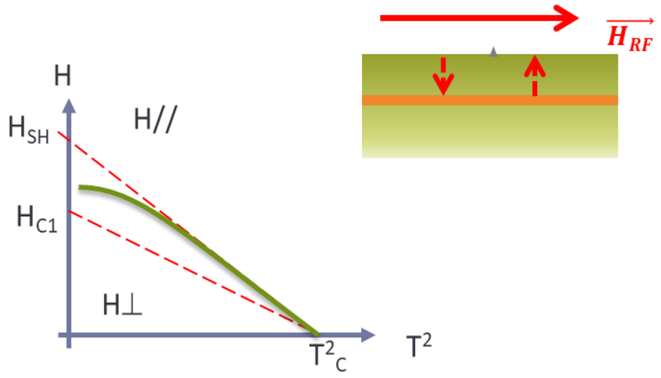
At stakes : reproducible large scale production

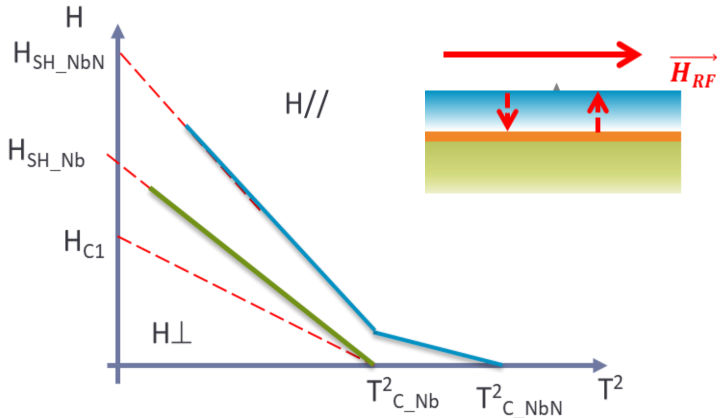
(Accelerators are big machines!)

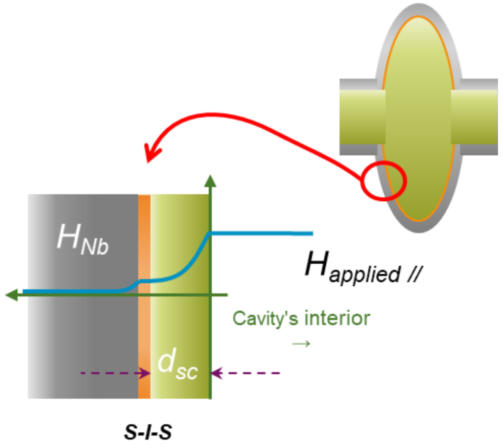
Multilayers (SIS) concept, or how to make theory face reality

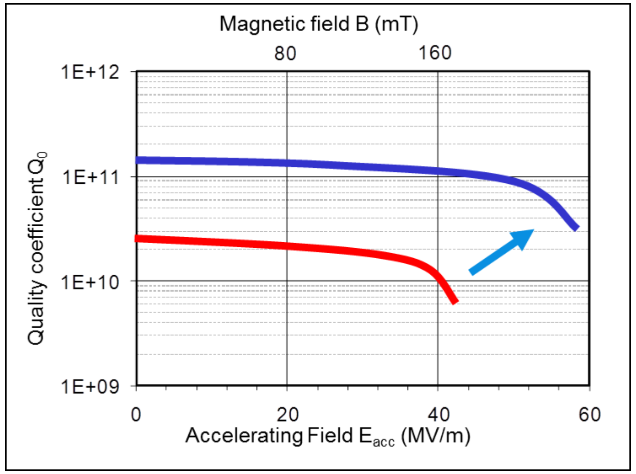












Some historical recalls about RF technology

Bulk Cu
= pure metal
Metallurgy
~- 6000 years

Bulk Nb
= pure metal
Metallurgy = ~ 6000 years
λ= 40 nm =>
+ Surface science: ~-100 years old

Higher Tc material
= Alloys, Compounds
+ Chemistry = ~ 250 years old
+ Surface science: ~-100 years old

Thin films
Nb or Compounds
CVD/PVD = ~ 50 years

Meta-material
multilayers
Advanced deposition techniques = ~ some years

Improving RF technology:

- **Huge challenges in material science**
- **Vast parameter space to be explored**
- **Underfinanced for years:**
  - **Accelerators considered as dirty hardware by fundamental material scientists**
  - **Material science considered as alchemy by (most) accelerator scientists**

Most developments, though, financed by Accelerator Community
A few 100 k€ /Y/~10 labs
Definitively not enough (compared to e.g. magnet history)

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Objectives for WP9
Innovative superconducting cavities

Improve performance and reduce cost of SRF acceleration systems

Small community

- **We built together a global strategy to be able to produce Superconducting RF (SRF) cavities coated with a superconducting film. Not only IFast, (informal) WW collaboration**
- **It includes pursuing the optimization and the industrialization:**
  - **Substrates preparation (Nb, Cu), e.g. PEP, metallographic polishing**
    - **Pre-and post treatment (laser)**
    - **The production of seamless copper cavities**
  - **The optimization deposition techniques: MS, PVD, ALD… to get Nb, NbN, Nb_3Sn, V_3Si… thick films (µm) and/or SIS Multilayers (nm)**
- **Produce and RF test prototypes of SRF cavities at 6 & 1.3 GHz Easier to handle, fabricate, dissect to provide fast feedback**
- **Produce accelerator type 1.3 GHz cavities (feasibility assessment).**

IFAST WP9:
- 9 countries
- 15 institutes
- >50 participants

CERN, DESY

Not officially!!!?

	IFAST WP9 Partners	Leading	Participating
1	CEA (Saclay, France)	WP, Tasks 1 and 4	Task **1**, 2, **4**, 6
2	CNRS/IN2P3/IJCLab (Orsay, France)		Task 1, 4
3	IEE-SAS (Bratislava, Slovakia)		Tasks 2-6
4	INFN/LNL (Legnaro, Italy)	Task 2	Tasks 1, **2**, 3, 5, 6
5	*INFN/LASA (Milano, Italy)*		Tasks 2, 3
6	*Piccoli S.r.l. (Noale (VE), Italy)*		Tasks 2, 3
7	Helmholtz-Zentrum Berlin (Berlin, Germany)	Task 6	Tasks 1 and **6**
8	RTU (Riga, Latvia)	Task 5	Task **5**
9	University Siegen, (Siegen, Germany)		Tasks 2, 3, 6
10	UKRI/STFC/ASTeC (Daresbury, UK)	WP, Tasks 1 and 3	Tasks 1, 2, **3**, 5, 6
11	*Lancaster University (Lancaster, UK)*		Tasks 1 – 3, 6
12	*Jlab (Newport News, Virginia, USA)*		Tasks 1, 2
13	*PTI (Physical-Technical Institute, Minsk, Belarus)*		Tasks 1, 2
14	*MEPHI (National Research Nuclear University, Moscow, Russia)*		Tasks 1 - 3
15	*Helmholtz-Zentrum Dresden-Rossendorf (Dresden, Germany)*		Tasks 1 – 3, 5

WP9:Planning Deliverables, Miles stones

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2021				-	M1 Quick Off meeting	M2	M3	M4	M5 WP9 meeting	M6 MS 42 (9.6) RFQ samp. Done	M7 WP9 meeting	M8
2022	M9	M10 WP9 meeting	M11 Steering committee (Mar 2nd)	M12 MS 38 (9.2) MS 39 (9.3)	M13 Annual meeting WP9 meeting	M14	M15	M16	M17 TFSRF WS in JLAB	M18	M19	M20
2023	M21	M22	M23	M24 MS 40 (9.4) ALD syst for cavities	M25	M26	M27	M28 MS 37 (9.1) TFSRF WS in Saclay	M29	M30	M31	M32
2024	M33	M34	M35 D 9.1 TF roadmap	M36 D 9.3 MS 41 (9.5)	M37	M38	M39	M40	M41	M42	M43	M44
2025	M45 D 9.5 Cav laser irr	M46 D 9.2 D 9.4 D 9.6	M47	M48				-	-	-	-	-

MS 38/ 9.2 : seamless copper 1.3 GHz*

MS39/9,3 : Coating facility built and tested at STFC, USI and INFN

* Task done, report delayed <1month

MS42/ 9.6 : QPR samples ready

D 9.3 : 6 GHz cavity coated and tested

MS 41 (9,5) : facility for laser operation 1.3 GHz

D 9.2 : RF test of a coated cavity

D 9.4 : ML coated cavity

D 9.6 : 4 types films tested on QPR

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Task 9.1:

Coordinators : Oleg B. Malyshev (UKRI) / Claire Antoine (CEA)

- **Coordination and strategy for innovative SC accelerating cavities**

  5 WP9 Meetings so far

  Mostly reporting, mostly Oleg doing all the work (I am ashamed ☺)

  On scopes :

  - Coordinating with DESY/CERN
  - Coordinating with Thin films TTC group
  - Snowmass letter of interest
  - Preparation of the 2022 thin films workshop
  - Preparation of SRF 2023
    - Several members of WP9 are also implied in those initiatives

  (too bad we could not gather all European TF activities together in a common project)

  Later

  - Preparation of the 2024 thin films workshop (scientific committee + local organization)
    - Will be held @ Paris-Saclay
    - Officially sponsored by IFAST

  Later

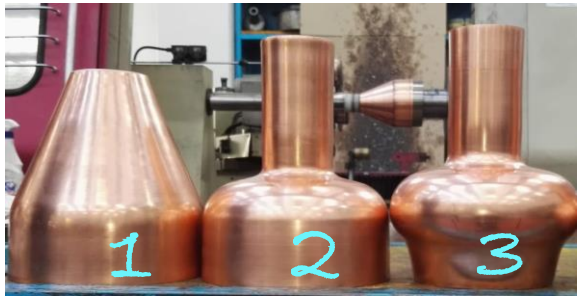
  - Preparation of the road map report: implement our expertise in the organization of future Int[l] thin film R&D

Task 9.2:Seamless elliptical copper cavities

GOALS:

Task Leader: Cristian Pira (INFN)

- Move cavity forming process from semi-automatic to fully automatic using CNC machine
- Study annealing temperature effect on formability
- Test reproducibility



- 6 GHz for task 9.3 and 1.3 GHz cavities for prototype

Why ?

- Need a lot of cavities for destructible tests
- Welding on copper definitively bad for films
- 18 cavities realized 6 GHz
- No intermediate annealing necessary
- I.FAST Milestone MS38 met

MS38: First seamless copper 1.3 GHz cavity produced as substrate for the coating of the SC film (Report)	M12

Task 9.3 Part 1: Cavity Coating and Evaluation

Task Leader: Reza Valizadeh (UKRI)

Aim:

- **Quick deposition, quick testing, low cost (6 GHz)**
- **Optimization of process parameters with A15 material**
- **Evaluation of SRF performance by deposition of high Tc superconductor inside a 6-GHz copper cavity.**

Nb_3Sn, NbTiN, NbN, MgB_2

Why?

- **Higher Tc SC are complex (compound) materials**
- **Composition needs to be adjusted to get best SRF performance**
- **Optimized recipes need then to be adapted for complex geometries**

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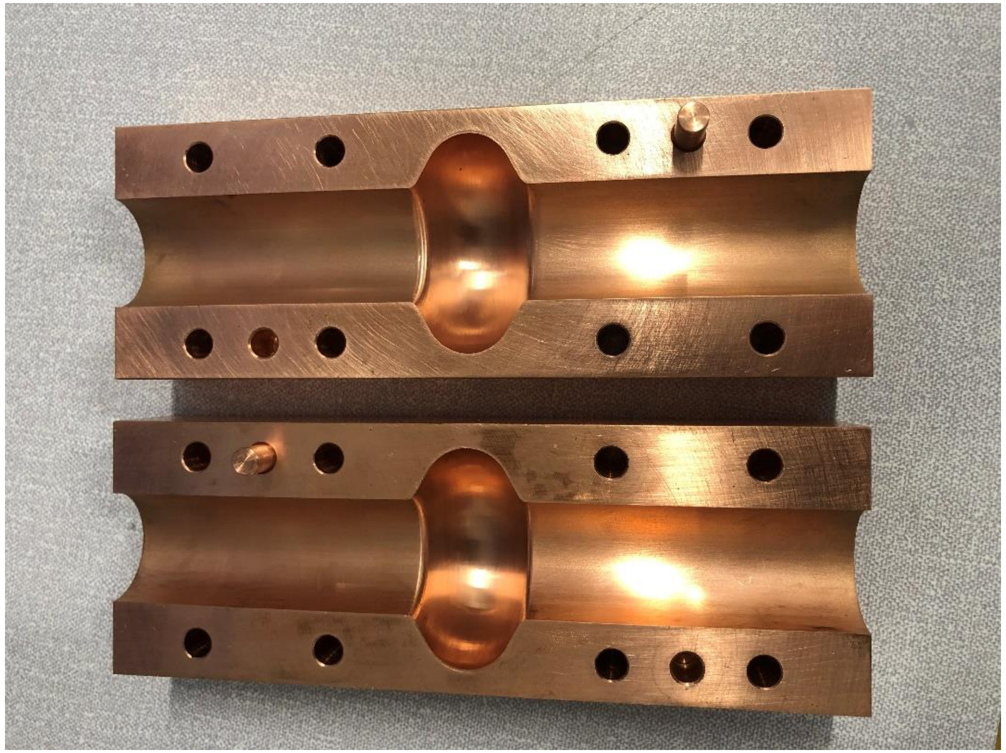
6 GHz copper cavity

- Two type of cavity is going to be explored at UKRI/STFC/DL

INFN seamless standard elliptical copper cavity

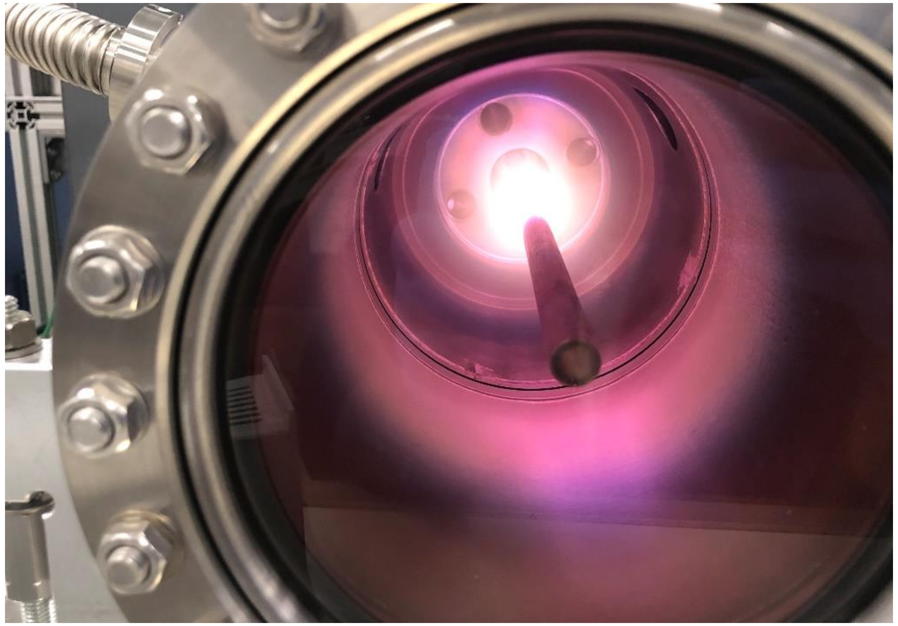


Lancaster University / STFC spilt cavity design

Deposition facilities for A15 SC: Techniques under development @UKRI

Hybrid physical chemical vapour deposition (HPCVD)

Permanent magnet cylindrical magnetrons
(several ø)



Deposition facilities for @ USI

High-power impulse magnetron sputtering(HiPIMS)

First Nb_3Sn samples by Magnetron Sputtering (DCMS) @LNL

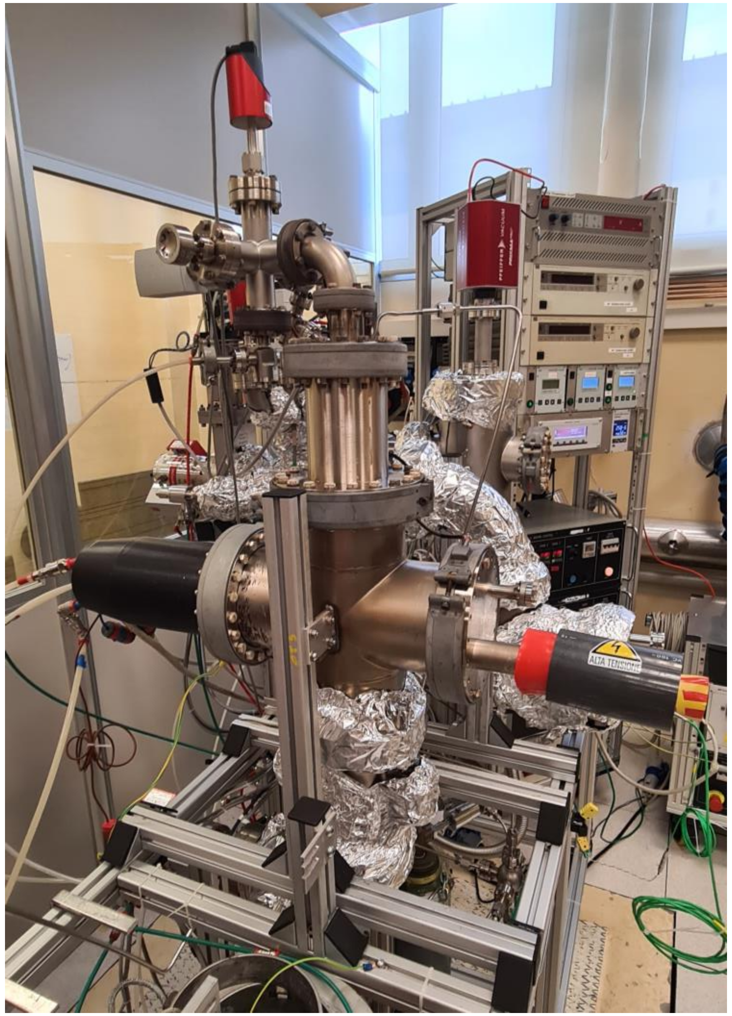
- **Deposition @ 1,86 – 3,58 W/cm^2**
- **XRD shows only Nb_3Sn phase**
- **Tc of 16 K on sapphire (post annealing 24h @750 °C)**
- **Tc of 12 K on Cu**

Buffer layer of Nb on next samples

Nb_3Sn coatings on sapphire, copper and quartz

Nb_3Sn 4” planar magnetron source @LNL

LNL Nb3Sn ycoating sstem



Also under development: Fabrication of Nb_3Sn tubular targets for MS by tin diffusion (dipping)

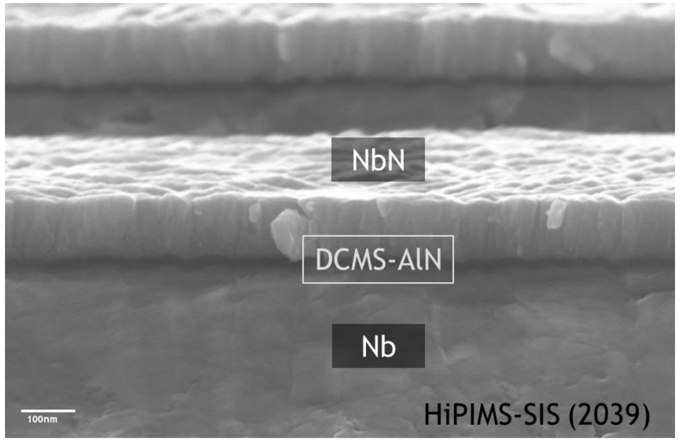
Task 9.3 Part Two:
Planar Samples & QPR deposition

Aim:

- **Optimise deposition parameters for other high T_c superconductor and provide sample for other partners for SRF evaluation of the SRF thin Films**

Why ?

- **Optimization of films still on going**
- **Alternative surface treatments**
- **Need to assess RF properties (see Task 9.6)**
- **Going from flat sample to complex shaped cavities is not straightforward => intermediate step**



HiPIMS-coated SIS structure on Si

Task 9.3 Part Two:
Planar Samples & QPR deposition

GOAL: Evaluate the effect of planar substrate Cu polishing on RF performance of QPR

INFN LNL
Lathe machining

INFN LNL
Chemical or Electrochemical Polishing

UNIVERSITÄT SIEGEN — Nb, NbN and SIS by HiPIMS

STFC ASTeC — Nb, Nb3SN, SIS by DCMS or HiPIMS

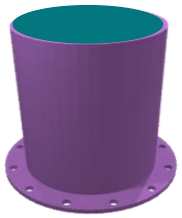
INFN LNL — Nb thick film by DCMS

cea SACLAY, Laboratoire de Physique des 2 infinis Irène Joliot-Curie, other partners...

HZB Helmholtz Zentrum Berlin

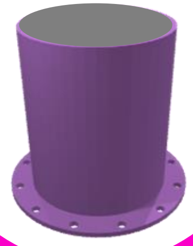
CERN

MECHANICAL MACHINING

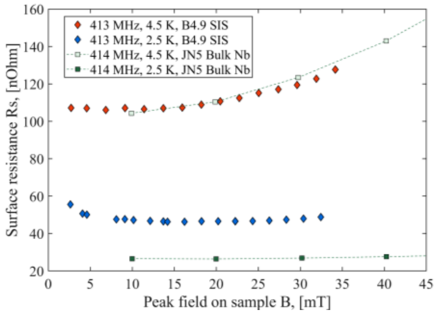


POLISHING

COATING



RF TEST



Courtesy of C. Pira (INFN) and E. Chyhyrynets

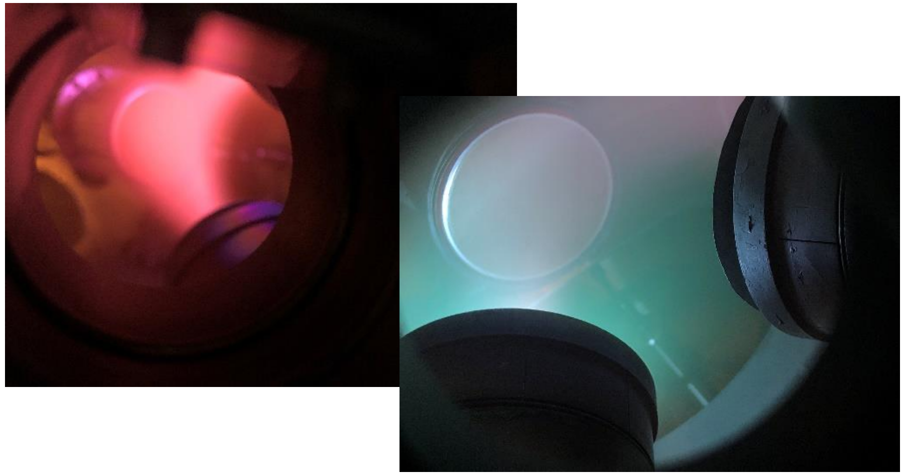
QPR Deposition of SIS multilayers

On going: **@UKRI**

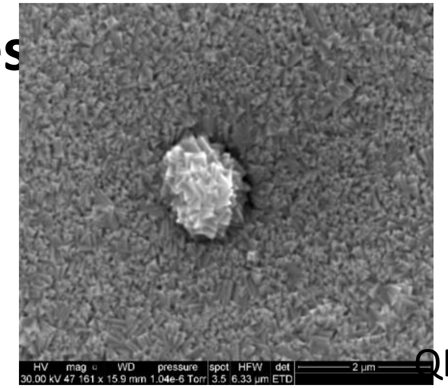
- **Nb bulk/AlN/NbN**
- **Diamond turned Cu Nb/AlN/NbN**

Thorough material characterization …

- **Opt and confocal microscopy**
- **SEM, EDX and EBSD**
- **Ion beam miller for cross-section**
- **X-Ray, TEM … advanced characterization techniques**



Plasma in the deposition chamber during Nb ← and AlN → deposition



SEM: HIPIMS Multilayer Nb/NbN

QPR sample after deposition

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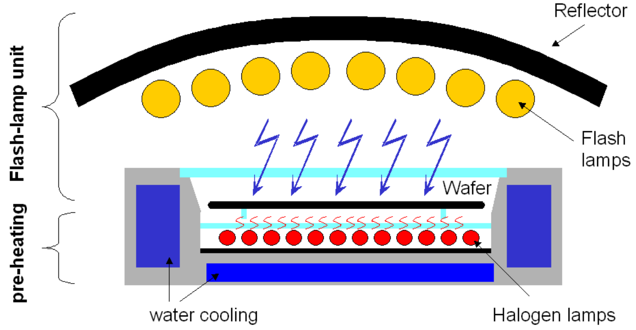
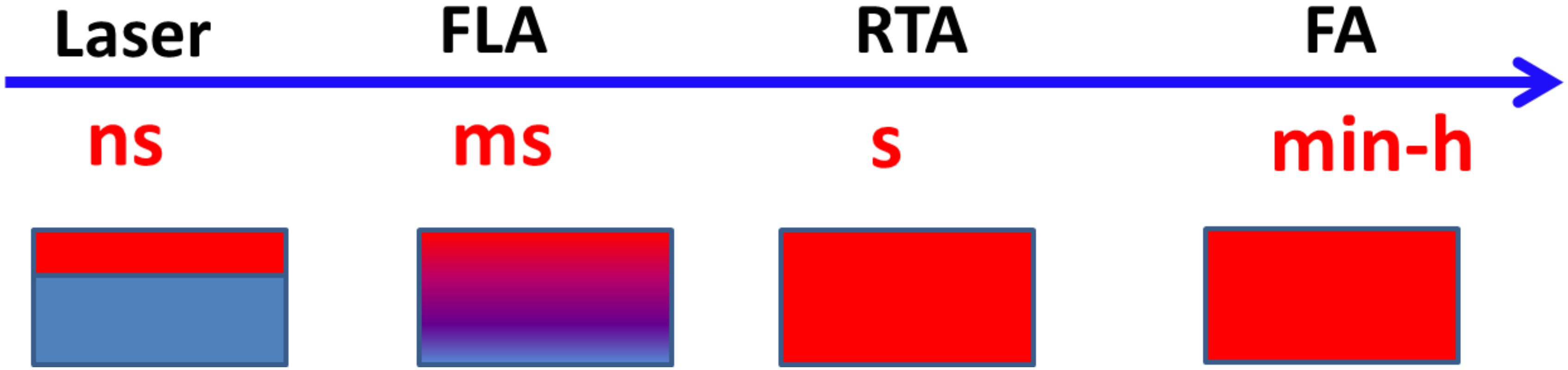
New surface treatment

Material processing:

- flash lamp annealing @HZDR
  - Issued from semiconductor industry

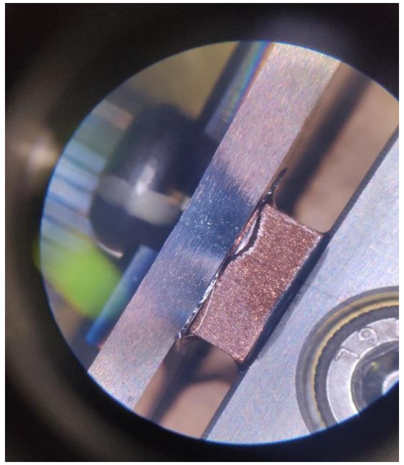




- Metallographic polishing @ IJCLab
  - Industrialization of metallographic lab procedure (minor damage layer)

Future plasma cleaning @ IJCLab

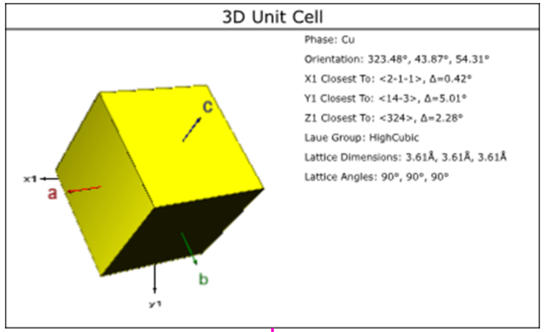
Characterization: e. g. Multi-layers @UKRI

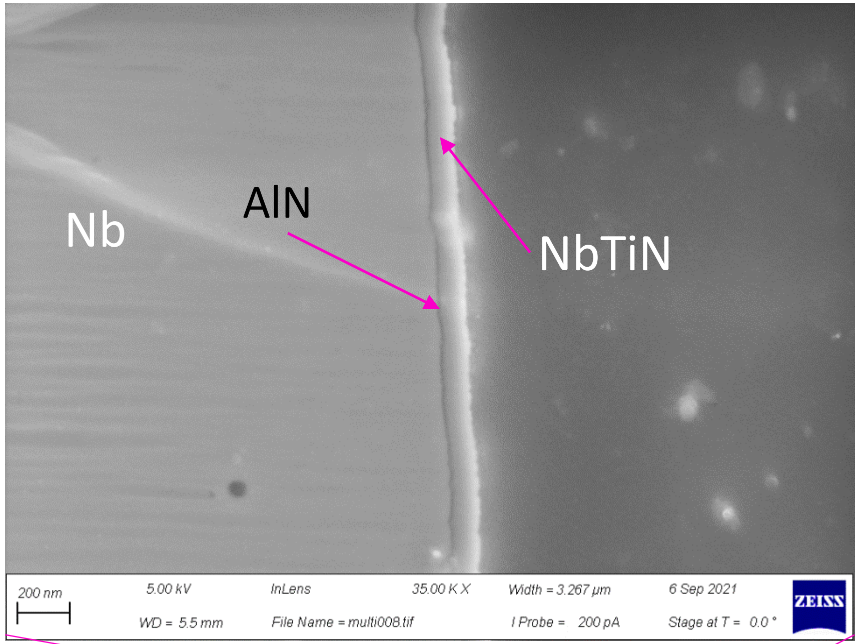


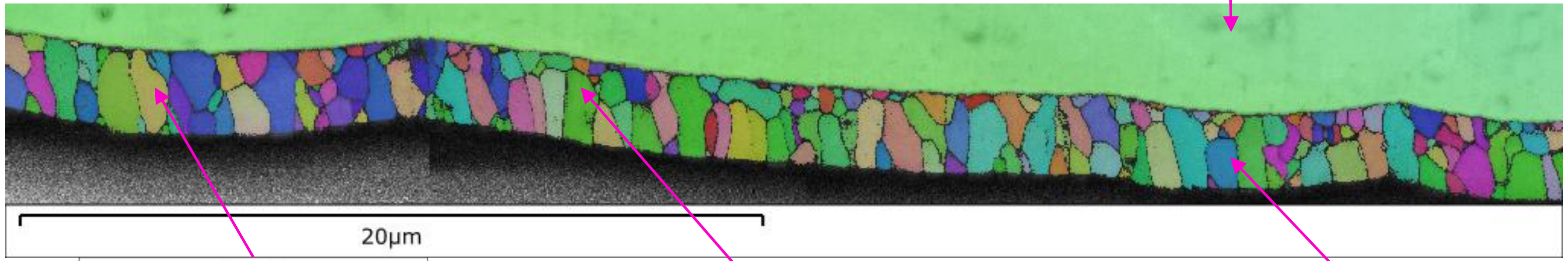
QPR sample after deposition

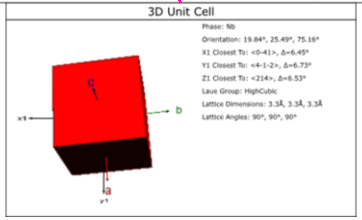
SEM cross section →

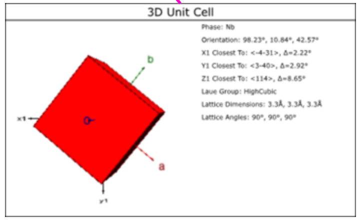
Detailed EBSD of Nb section ↓

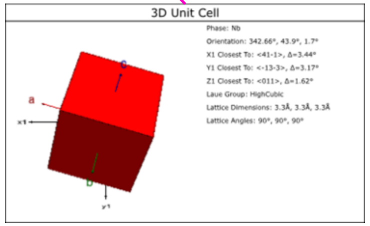


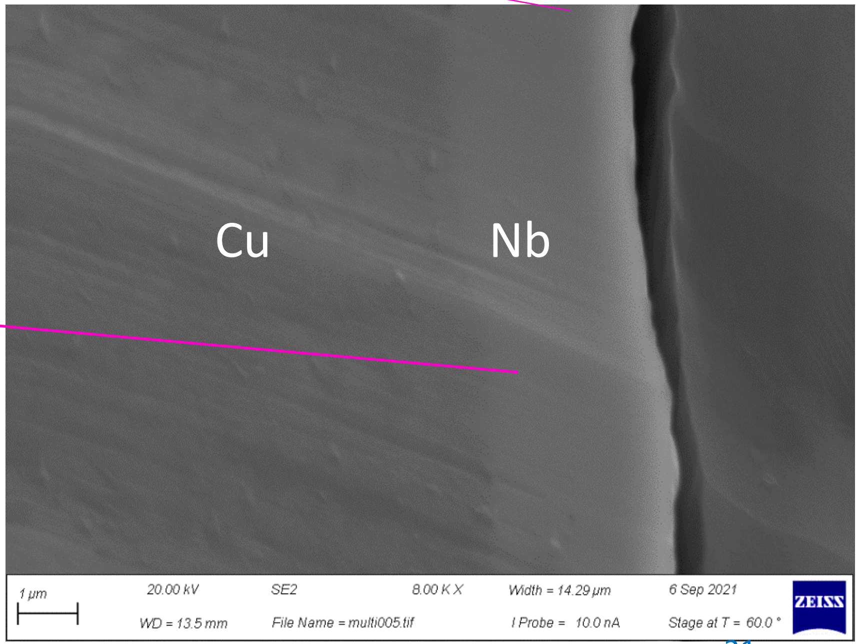












Diamond turned Cu Nb/AlN/NbN

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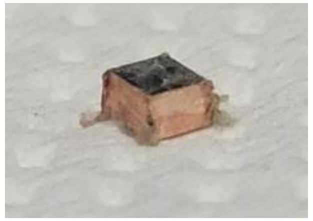
Superconducting Properties Evaluation at IEE

- DC magnetisation measurements using *Vibrating Sample Magnetometer*
- Small planar samples (~ 2 mm x 2 mm – *cutting*)

small sample

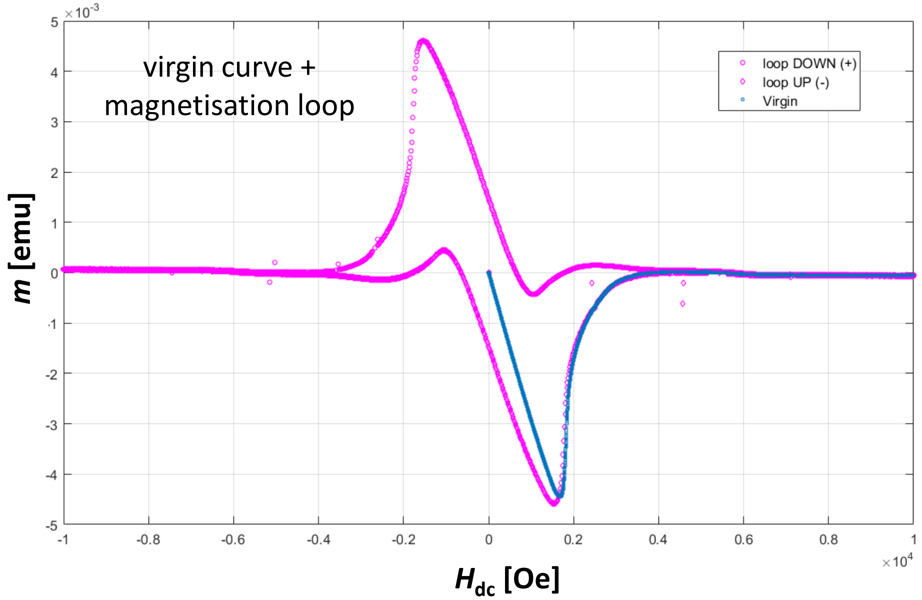


cutting phase (disk saw)

VSM sample holders

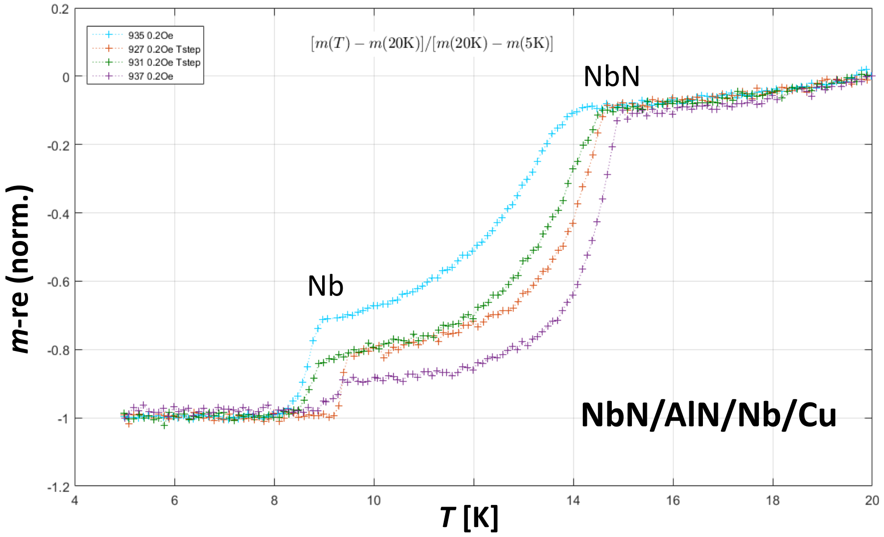
parallel *H*

perpendicular *H*

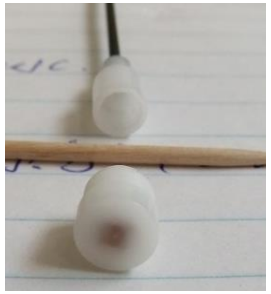


- *AC susceptibility* – temperature scans

Determining T_c of different films in Multilayer and SIS samples

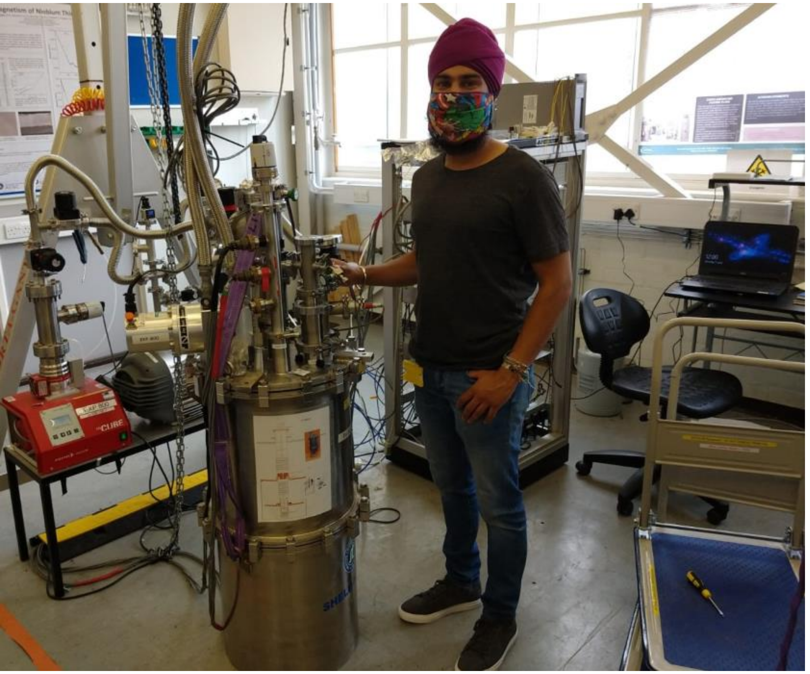


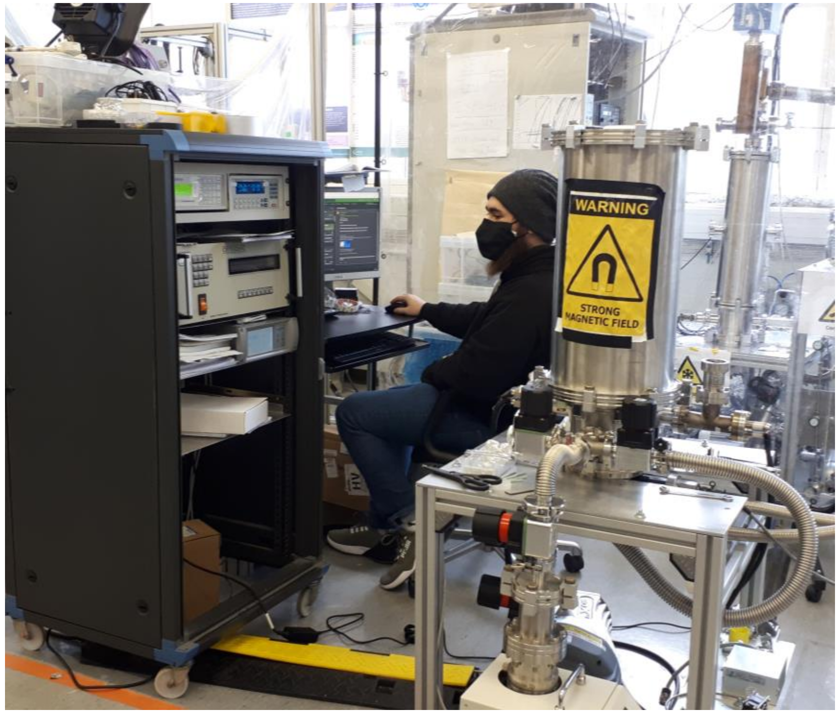
AC susc. sample holder

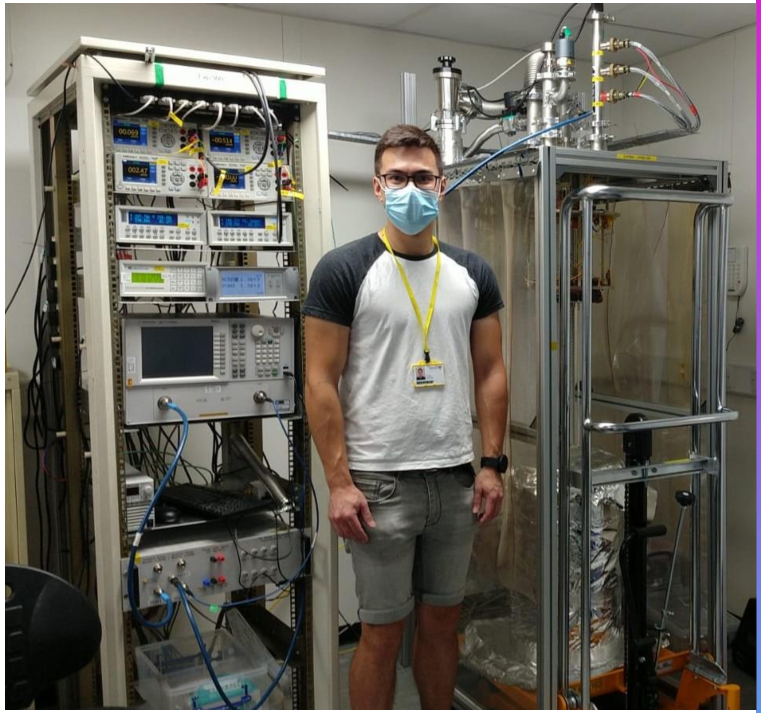


Courtesy of E. Seiler

Superconducting Properties Evaluation at UKRI/STFC/CI







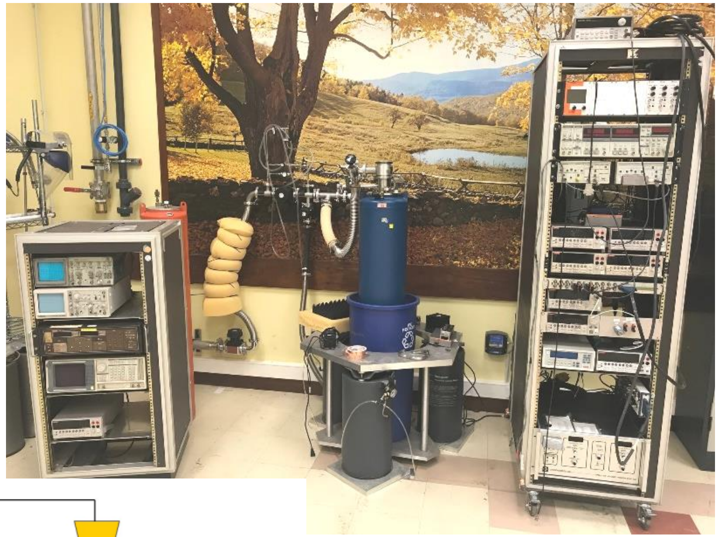
EXP800: RRR, Magnetic field penetration
+ 2 other experiments (in-He-gas)

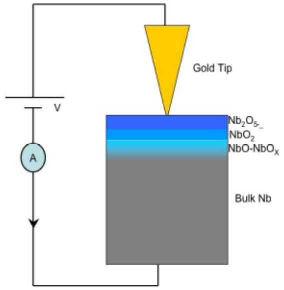
EXP700: Magnetic field penetration facility (in-vacua)

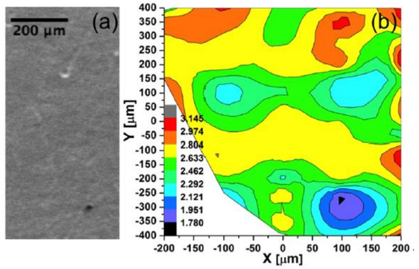
EXP900: R_S measurements with 7.8 GHz cavity

Courtesy of T. Sian

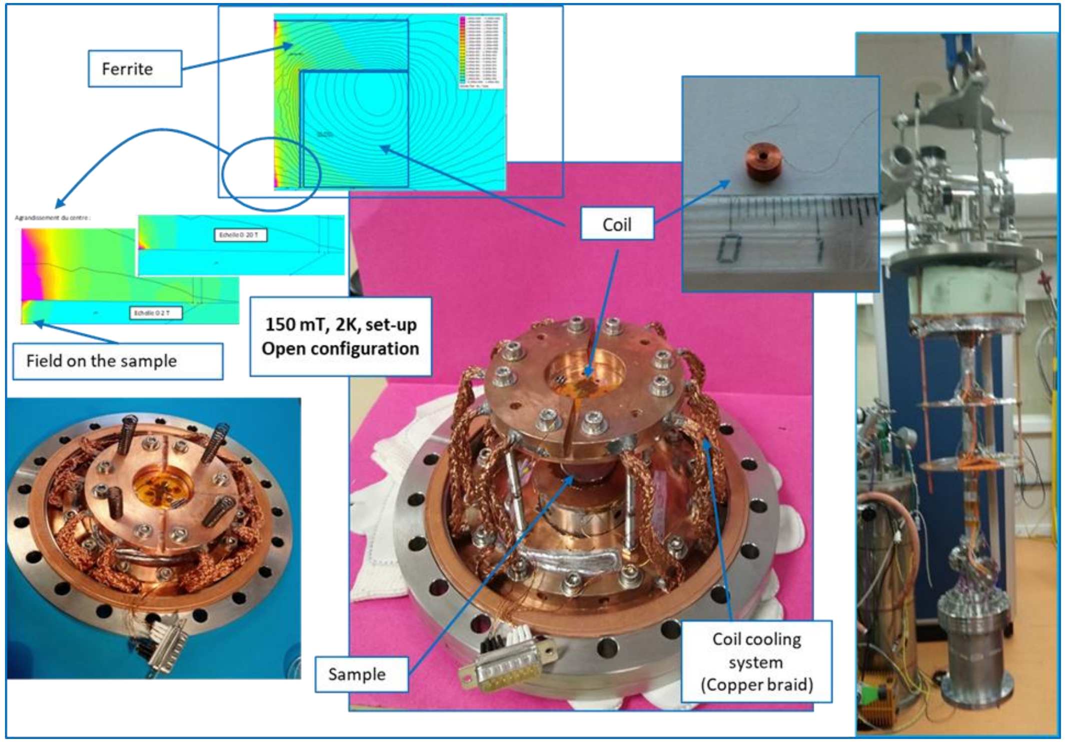
Superconducting Properties Evaluation at CEA Saclay







Tunneling microscopy
Superconducting gap



Local magnetometry
Penetration field

Task 9.4:Surface engineering by atomic layer deposition (ALD)

Task Leader: Thomas Proslier(CEA)

Aim:

- **Deposition of functionalized layers :**
  - **Low secondary yield cap layer (↓ multipacting)**
  - **SIS multilayers**
  - **Dielectric surface engineering and doping**
- **Development of a 1.3 GHz deposition set-up**

Why ?

- **ALD = highly conformational => adapted to complex shapes**
- **Chemical technique => wide range of compounds manageable in the same deposition set-up**
- **Can be used to upgrade Bulk Nb cavities**

ALD Example: deposition of TiO_2 .

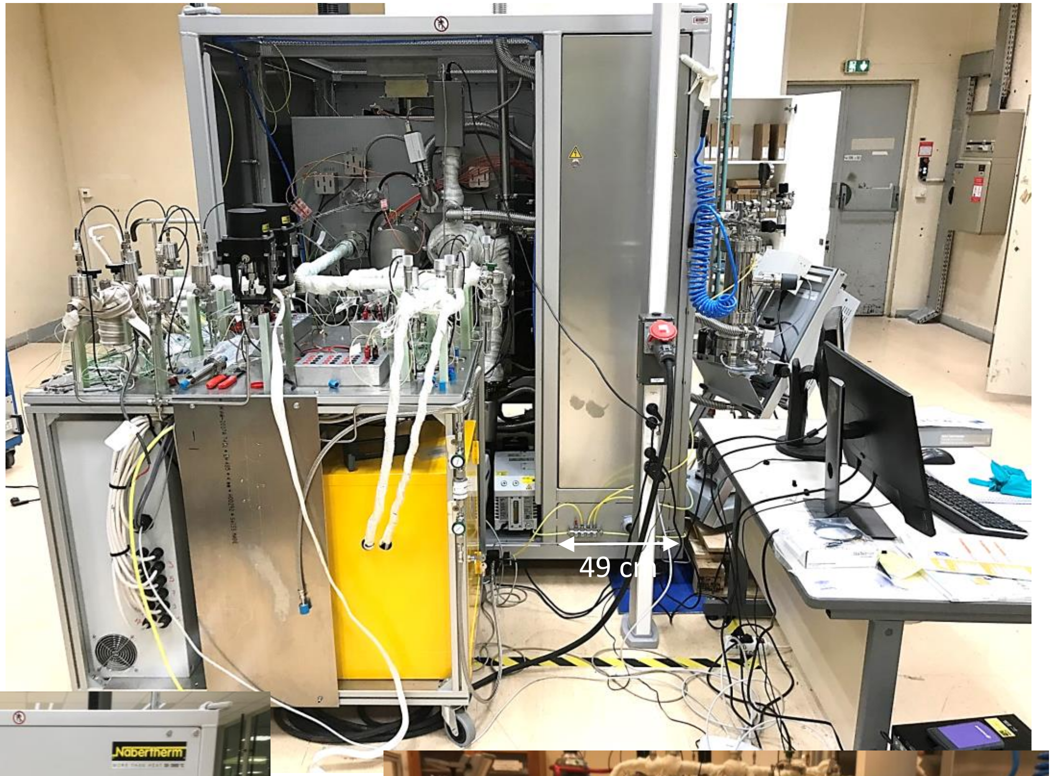
Principle

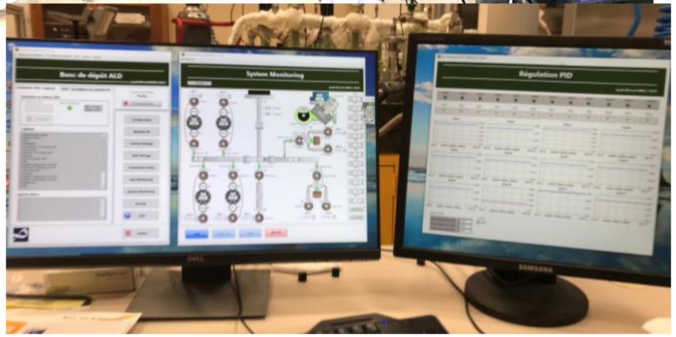
- **Chemical precursors (gaz)**
- **Precursor 1 : adsorbed (chemisorbed) on the surface**
- **Purge (neutral gas)**
- **Precursor 2 : reacts w. precursor 1 directly on the surface => adapted to complex shapes like cavities (no line of sigth issues)**

Extract from http://www.youtube.com/watch?feature=player_detailpage&v=XMda8TXLIFk

NEW ALD system @ CEA

- High vacuum oven:
  - 650°C – 10^{-6} mbar / 900°C 1bar N_2
  - Volume retort: Φ = 49 cm, L= 110 cm (1.3, 0.7 GHz cavities)
- ALD system:
  - 9 precursor lines (2 gases, 2 liquids, 4 solids, 1 Ultra high temp.).
  - RGA synthesis monitoring.
- Interface and control:
  - Labview program of ALD system and Oven.
  - Automatic synthesis parameter control (overnight dep.) and monitoring.
- Status:
  - Deposition tests on samples
  - Future: Deposition on cavities





Soon ready for 1.3 GHz cavity deposition

Task 9.4 results summary

- Atomic Layer deposition strength is its scalable capability: from bench to industrial scale (coupons to cavities and much more high aspect ratio and large surface objects).

Achievement within IFAST task 9.4:

- Control and reduction by ALD of the secondary electron yield and the resulting multipacting mitigation.
- Control and optimisation of the superconducting multilayer properties by ALD (T_c =15K).
- Homogeneous deposition and multilayer properties on Nb and Cu 1.3 GHz cavities.
- Compatible with cavity surface treatments (stability after HPR, thermal treatments…)
- New doping approach and dielectric layer engineering by ALD.

Task 9.5: Improvement of mechanical and superconducting properties of RF resonator by laser radiation

Task Leader: Arturs Medvids (RTU)

Aim:

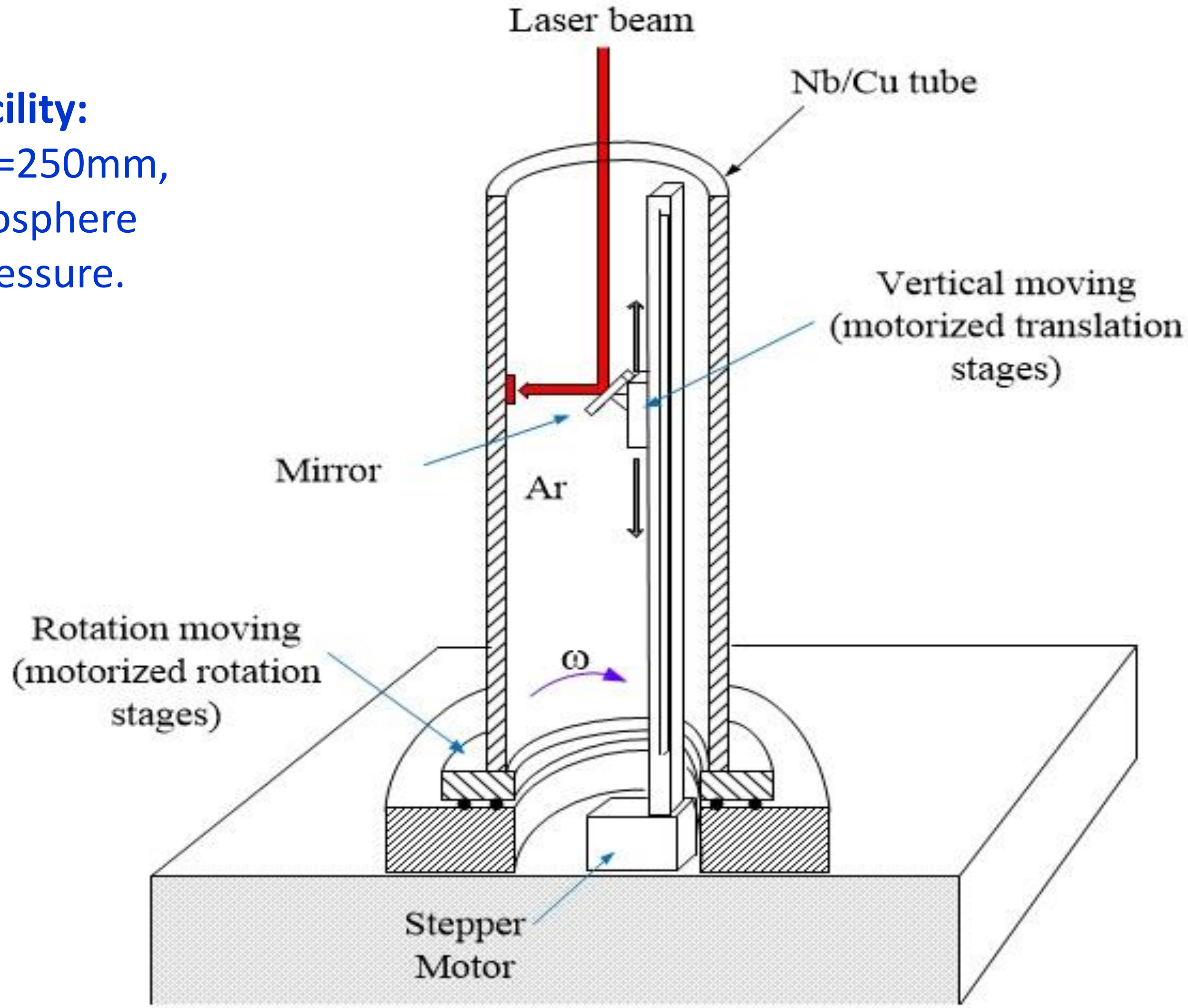
- **Pre-and Post-surface Laser treatment**
  - **On copper, to improve film deposition**
  - **On deposited films, to improve their crystalline quality**

Why ?

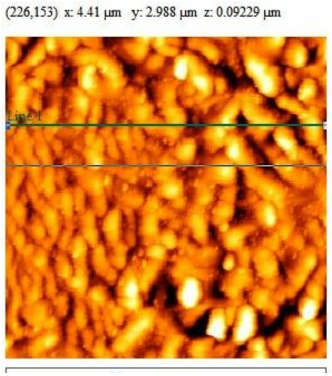
- **Smoothing of surfaces**
- **Recrystallization**
- **Decreasing porosities**

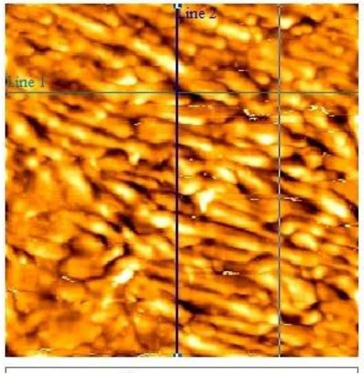
Cross-section of the laser facility for irradiation inner surface of RF cavity

Laser facility:
L=450mm, D=250mm,
Ar gas atmosphere
1.5 atm pressure.

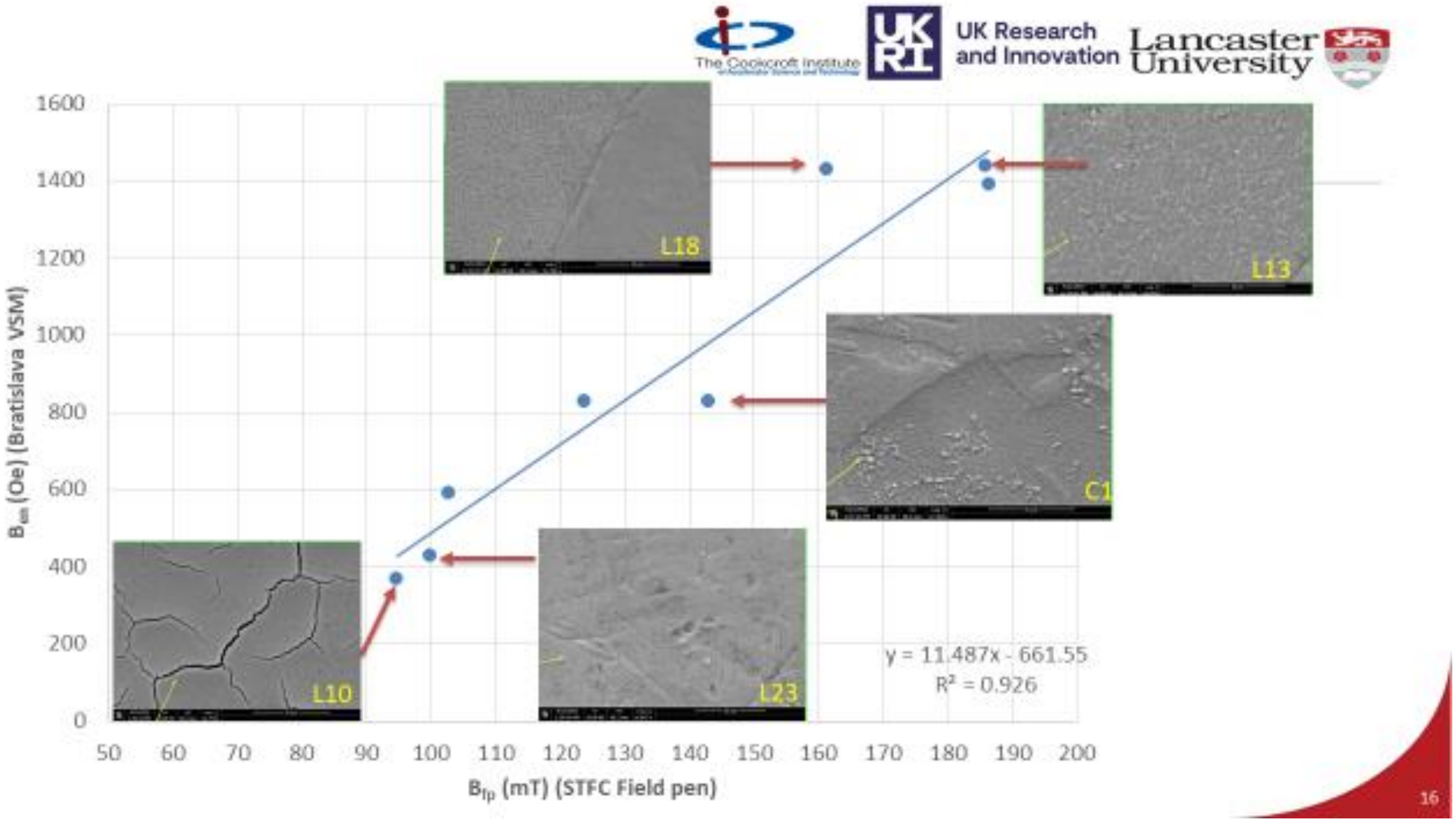


Now we are making a vacuum chamber with an optical window.
And we wait for the results of the purchase competition of two motors for the chamber: stepper motor and motorized rotation stage.





Assesment of the efficiency of laser treatment



Task 9.6: Optimization of flat SRF thin films production procedure

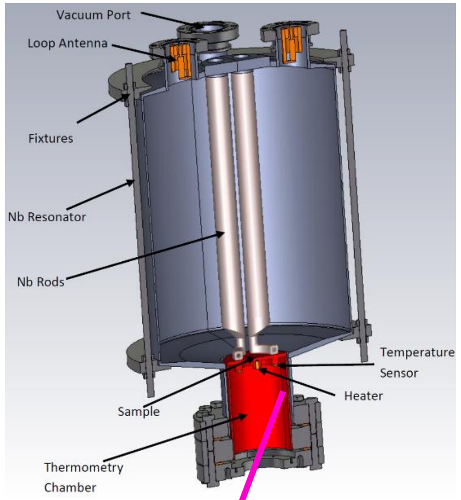
Task Leader: Oliver Kugeler (HZB)

Aim:

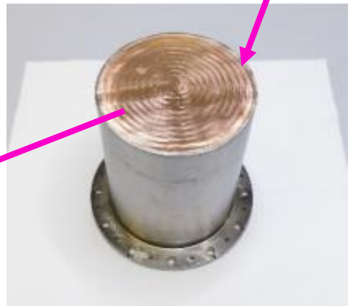
- **RF testing of the films developped throughout the WP9**
  - **Sample is small enough for easy handling**
  - **Smaple is flat (one problem less in the way)**
  - **3 ≠ frequencies available : large exploration (R_{BCS} vs R_{res}**

Why ?

- **Material characterization, even advanced are still not predictive of future RF behavior**



QPR



Flat sample for RF testing

MS42: First seamless copper 1.3 GHz cavity produced as substrate for the coating of the SC film (Report)	M6

Task 9.6:Optimization of flat SRF thin films production procedure

Lathe machining

Chemical or Electrochemical Polishing

UNIVERSITÄT SIEGEN — Nb, NbN and SIS by HiPIMS

STFC ASTeC — Nb, Nb3SN, SIS by DCMS or HiPIMS

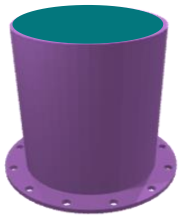
INFN LNL — Nb thick film by DCMS

cea SACLAY, Laboratoire de Physique des 2 Infinis Irène Joliot-Curie, other partners...

HZB Helmholtz Zentrum Berlin

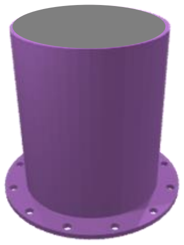
CERN

MECHANICAL MACHINING

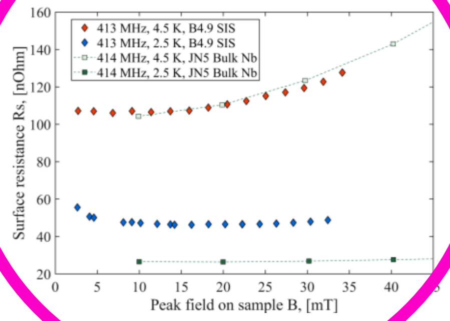


POLISHING

COATING

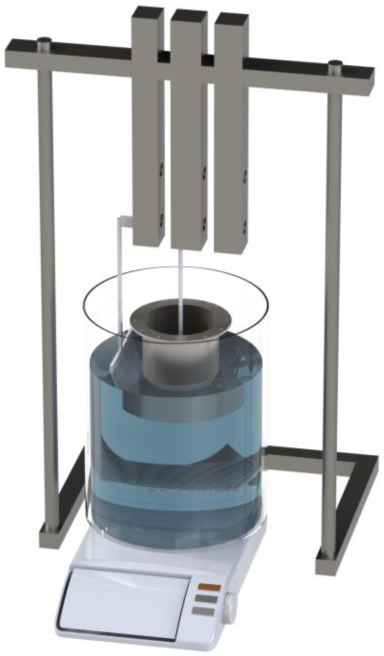


RF TEST

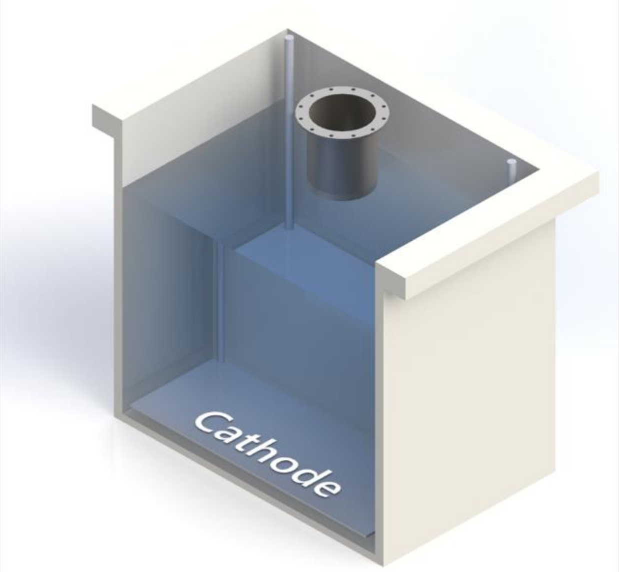


Courtesy of C. Pira (INFN) and E. Chyhyrynets

Plasma electropolishing on QPR samples @ INFN

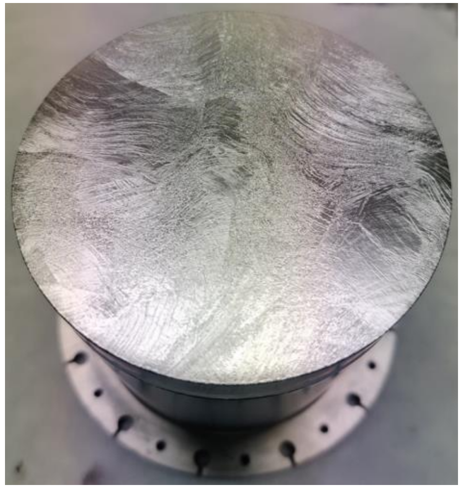


Old system

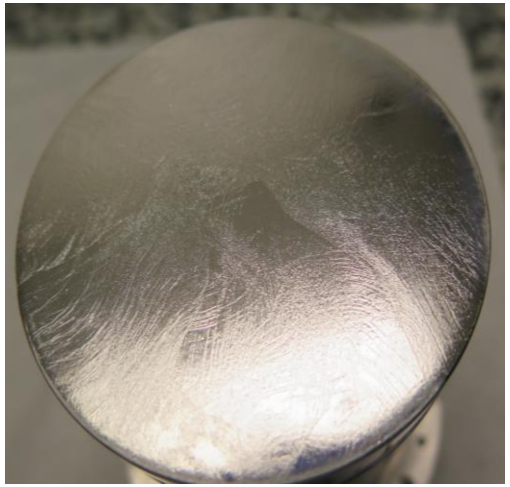


Upgraded system

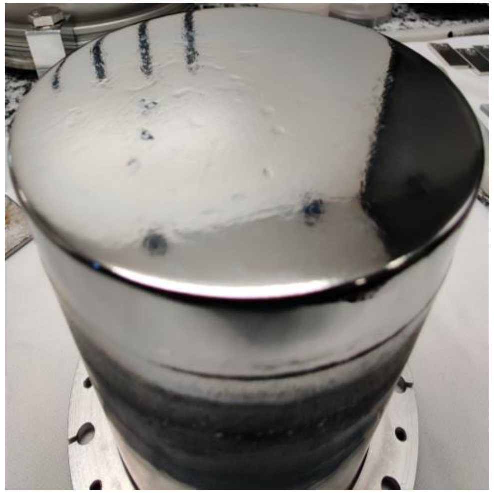
- Larger volume
- More stable temperature
- More stable current



Initial Nb QPR sample

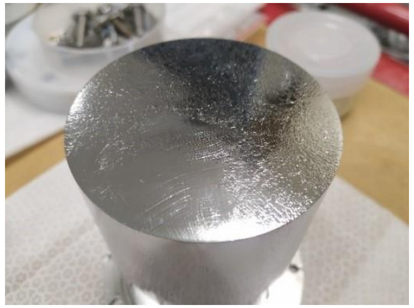


Surface improvement after 10 min

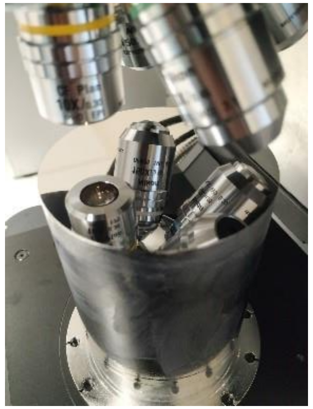


100-µm removal in 60 min.
Mirror finish

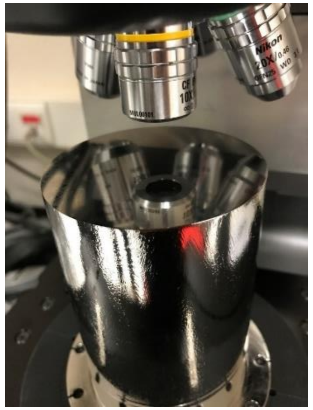
Metallographic polishing @ CEA/IJCLab



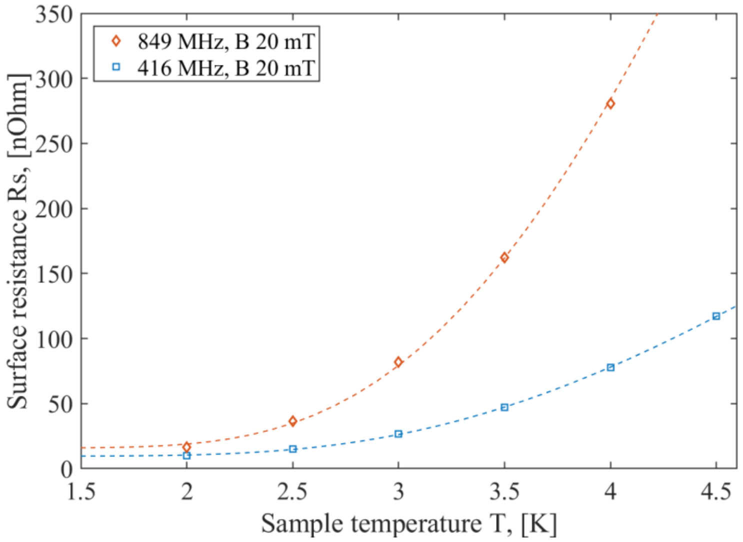
QPR sample milled from
ASTM0 large grain material
Poor RF performance,
In contaminations



Mirror polishing
at IJCLab



After EP 150 µm +
annealed at 900°C
under vacuum +
EP 20 µm at CEA



Great RF performance of baseline sample
(9 Ohm residual resistance at 416 MHz)

Pictures courtesy Oleksandr Hryhorenko (IJCLab)

WP9: 6 months prospectives

- **Task 9.1:** participation to TFSRF and SRF conference programs
  - *CEA, INFN, HZB, UKRI, USI, JLab MEPHI, PTI.*
- **Task 9.2**: start the production of Cu 1.3 GHZ, process optimization
  - *INFN-LNL, INFN-LASA, PICCOLI, UKRI, USI, CEA, IEE, HZB, PTI, MEPHI*
- **Task 9.3** : first deposition processes protocol defined
  - Depositing 6 GHz @UKR, @INFN, RF testing @ INFN
  - Depositing and testing split cavities
  - *UKRI, INFN, IEE, ~~USI,~~ HZB, MEPHI, HZDR*
- **Task 9.4**: deposition on test samples, then cavities
  - *CEA, CNRS*
- **Task 9.5**: Completing the building up of a laser facility and testing it on a tube
  - *RTU, UKRI, INFN, IEE, HZB*
- **Task 9.6**: Testing QPR samples (many !) …
  - *HZB, INFN, UKRI, USI, CEA*

CONCLUSION

→ **Things are going according to IFAST WP9 plan**

→ **3 milestones already achieved.**

→ **Very nice "side effects", e.g.**

  → **Breakthrough side effect of QPR activities within I.FAST:**

  Significant improvement of measurement accuracy (< 4 nW)

  → **Reduction of SEY by ALD => reduction of multipacting**

iFAST

Thanks for your attention!

PS : who the hell invented this template/ Montserrat police !?

This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under GA No 101004730.