Study of Tl(1223) superconducting coatings for beam impedance mitigation in the Future Circular Collider

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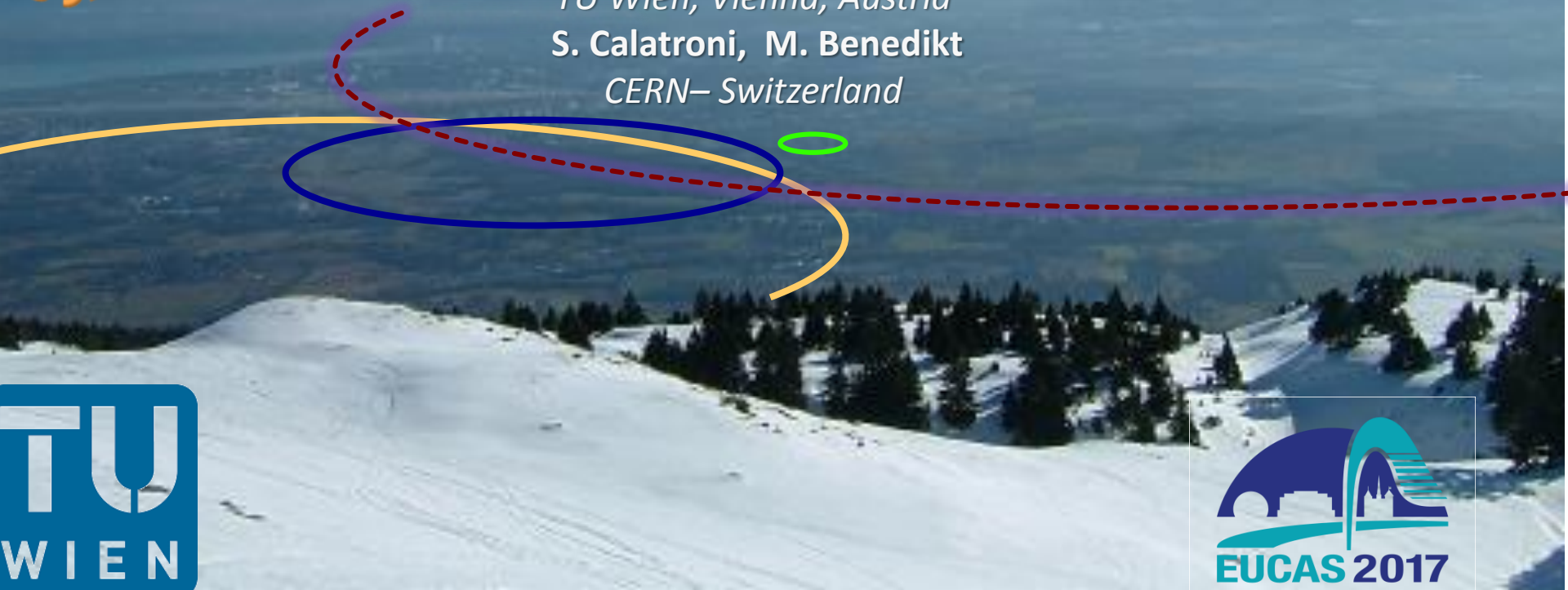
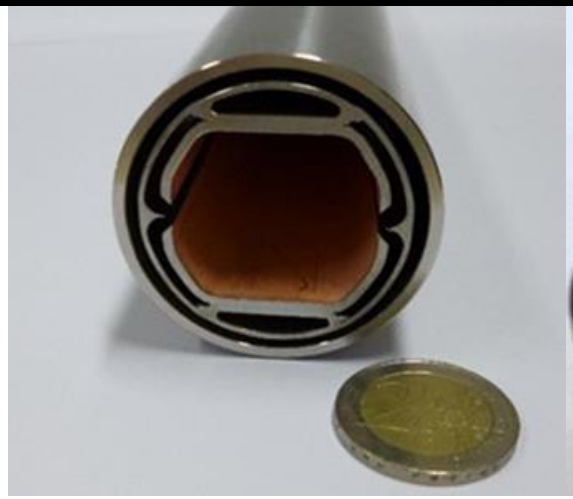


Synchrotron radiation/beam screen

High synchrotron radiation load (SR) of protons @ 100 TeV:

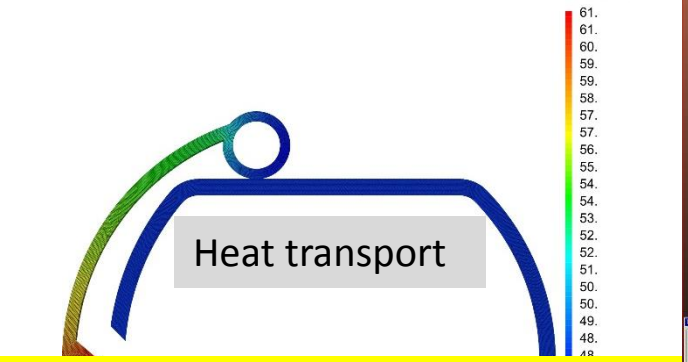
~30 W/m/beam (@16 T)

→ **5 MW total in arcs** (LHC <0.2W/m)

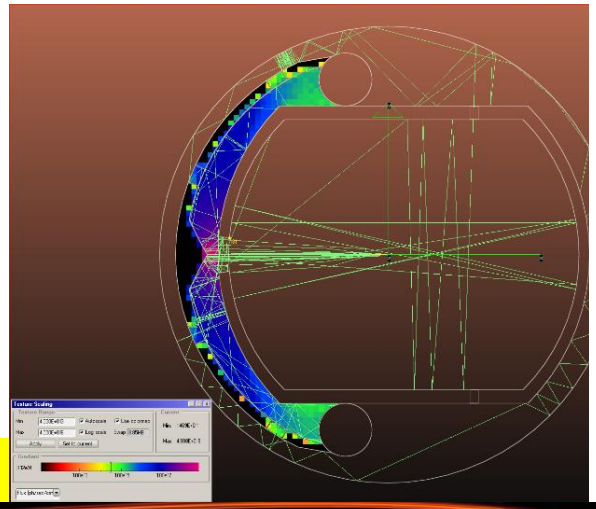


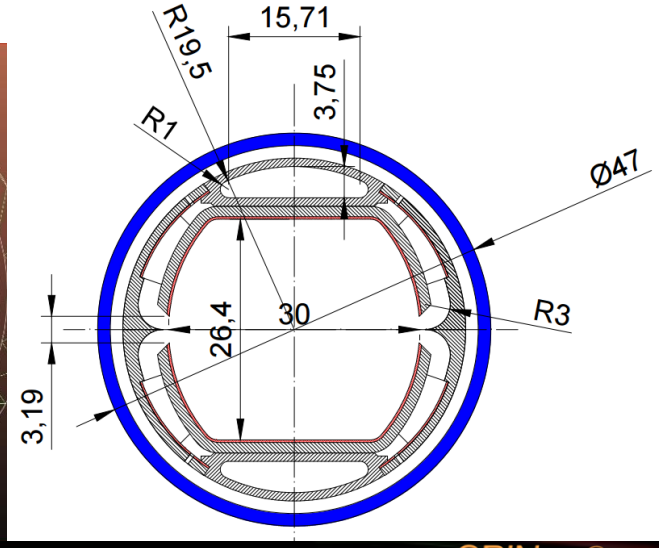
New type of ante-chamber

- absorption of synchrotron radiation
- avoids photo-electrons, helps vacuum
- **Optimum T_{screen} ~ 50 K**



R. Kersevan, C. Garion, L. Tavian, et al.





10^{11} protons will circulate in bunches in the ring at v≈c

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Proton are charged -> it will produce an EM field

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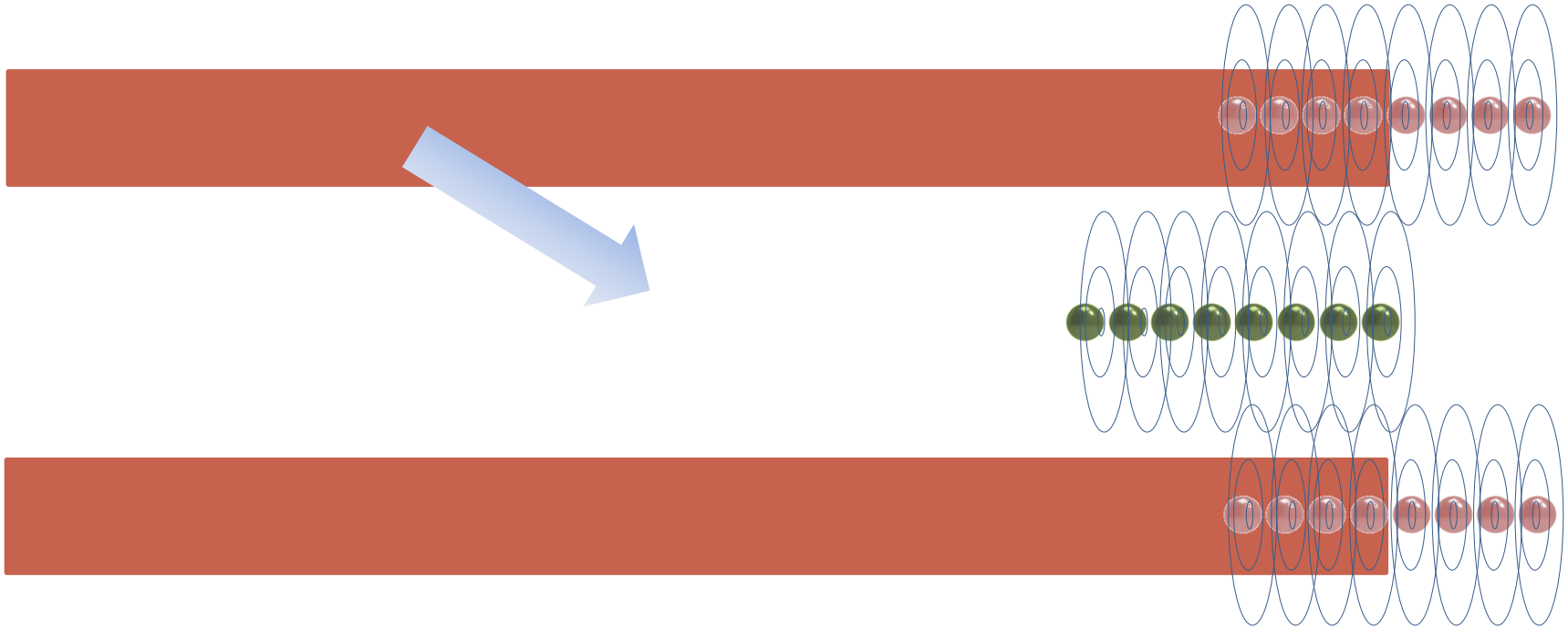
The EM Field will produce an image current in the screen

The image current will dissipate energy

10^{11} protons will circulate in bunches in the ring at v≈c
Proton are charged -> it will produce an EM field
The EM Field will produce an image current in the screen
The image current will dissipate
Due to the delay, it will affect back the beam causing instabilities.



The surface resistance of copper at 50 K may not be sufficiently low to guarantee a safe operational margin for the FCC-hh beams, in particular at injection energy.

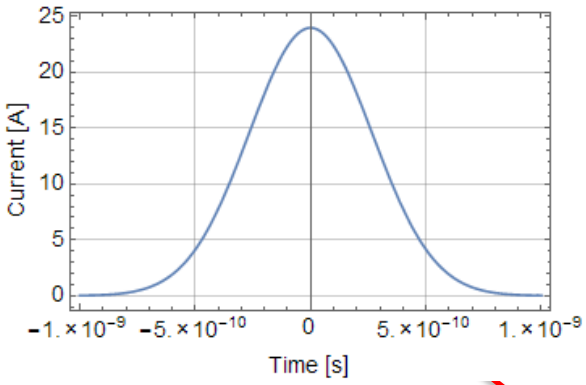
Introduction of a HTSC coatings to mitigate the beam impedance

Joint project to study this possibility

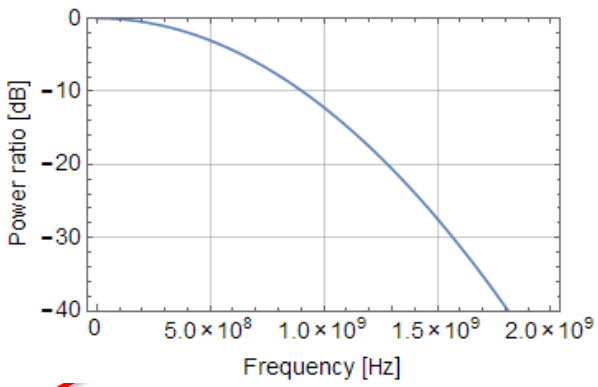
HTS films requirements for beam screen

Bunches of 10^{11} protons, 8 cm long

Image current in the screen



Frequency spectrum



Beam screen of 30mm diameter.

Assuming a film thickness / skin depth of 1 µm the HTS material should have a critical current density

Jc of about 25 kA/cm^2 (2.5x10^8 A/m^2) at 50 K and 16T 1GHz

At present NO superconductors have these performance!

HTS films requirements for beam screen

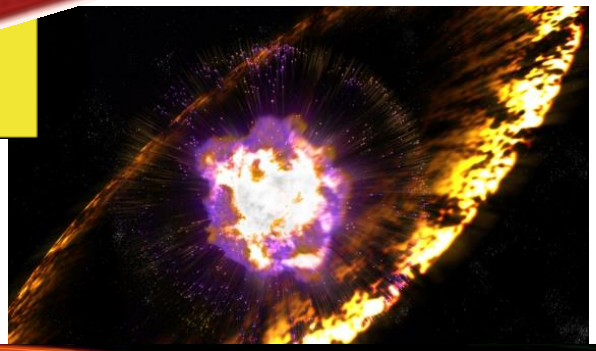
- T=50 K Very high operation temperature

- B=16 T Very High magnetic field

- ν=1GH

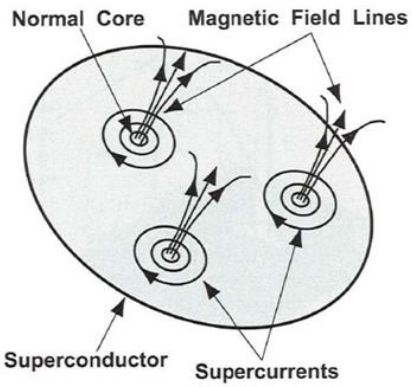
- High synci

- Boundary ma ials with 100 TeV particles
  (only supernova burst can exceed this energy)

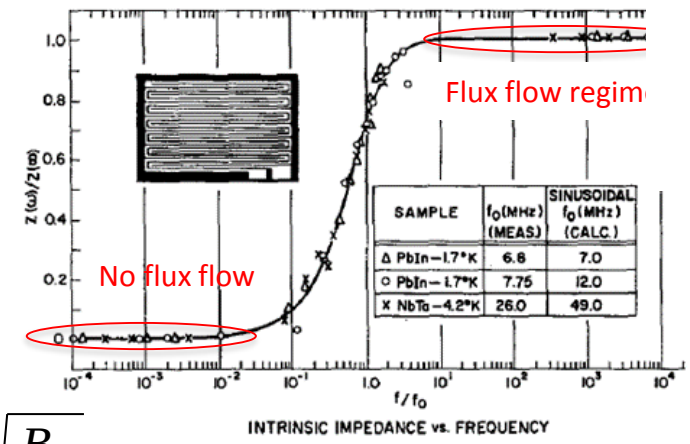


Surface resistance: general definition

$$R_s(H_{rf},T,B) = R_{BCS}(H_{rf},T,0) + R_{res}(H_{rf},0,0) + R_{fl}(H_{rf},T,B)$$



Flux flow depends on pinning strength and frequency



INTRINSIC IMPEDANCE vs. FREQUENCY

Gittleman and Rosenblum: Journal of Applied Physics 39, 2617 (1968)

IEEE TRANSACTIONS ON APPLIED SUPERCONDUCTIVITY, VOL. 27, NO. 5, AUGUST 2017

Surface Resistance of Superconductors in the Presence of a DC Magnetic Field: Frequency and Field Intensity Limits

Sergio Calatroni and Ruggero Vaglio

Abstract—We revisit the classical rigid-fluxon model which describes the effect of an applied magnetic flux on the RF surface resistance of a superconductor and discuss explicit formulations for a few limit cases. As an application, we discuss the role of magnetic flux on the enhanced surface resistance of RF accelerating cavities based on niobium, depending on its material properties. We also assess the conditions for the use of high-temperature superconductors for carrying the beam image RF currents in future high-energy circular hadron colliders such as the future circular collider being studied at CERN.

S. Calatroni and R. Vaglio: , IEEE-TAS 7, 3500506 (2017)

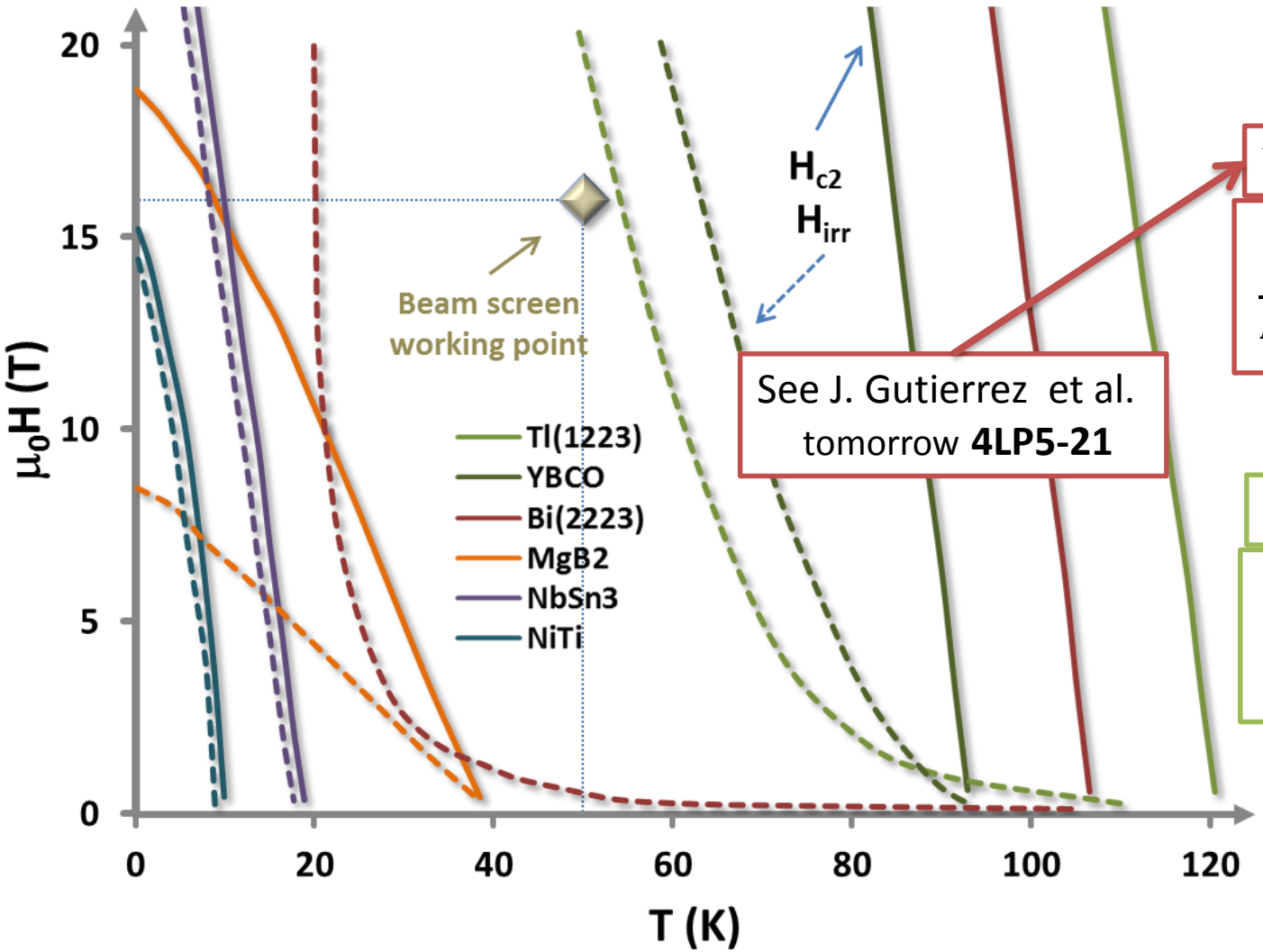
$$Z_{sf} \equiv Z_f = Z_n \sqrt{\frac{B_o}{B_{c2}}}$$

for $\nu >> \nu_o$

$$R_{sf} \equiv R_f = \frac{R_n}{\sqrt{2}} \sqrt{\frac{B_o}{B_{c2}}} \left(\frac{\nu}{\nu_0}\right)^{3/2}, \quad X_{sf} \equiv X_f = R_n \sqrt{2} \sqrt{\frac{B_o}{B_{c2}}} \left(\frac{\nu}{\nu_0}\right)^{1/2}$$

for $\nu << \nu_o$

Superconducting materials phase diagram



$$R_{fl} \approx \sqrt{\frac{B}{B_{c2}}}$$

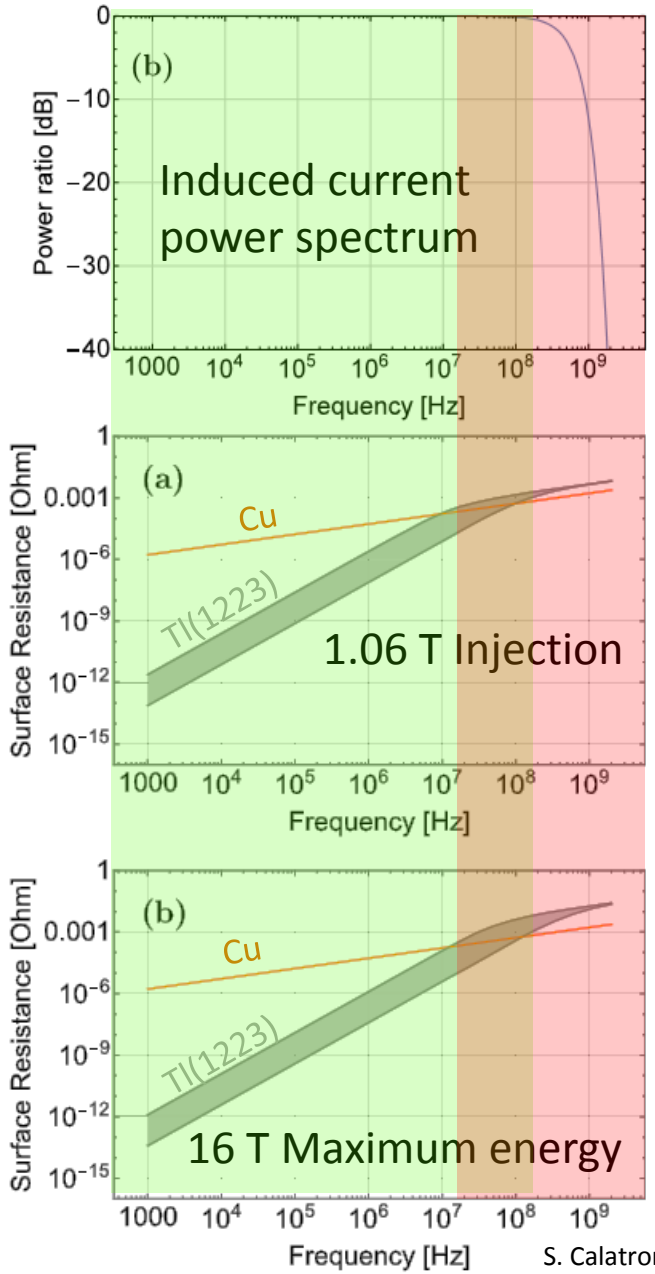
YBCO

$$\frac{H}{H_{c2}} = \sqrt{\frac{16\ T}{80T}} = 0.45$$

See J. Gutierrez et al.
tomorrow **4LP5-21**

Tl 1223

$$\frac{H}{H_{c2}} = \sqrt{\frac{16\ T}{140T}} = 0.33$$



Tl(1223) estimated surface resistance

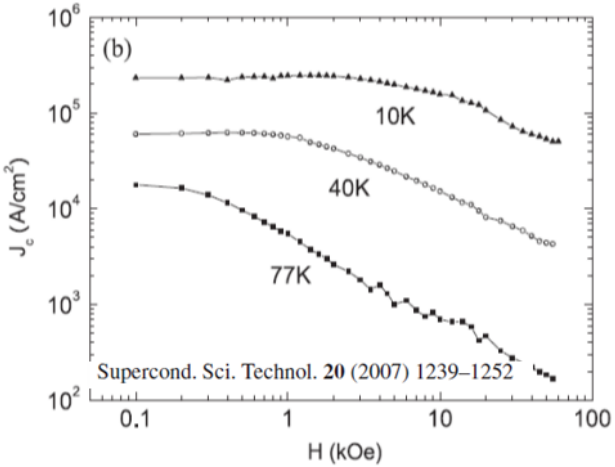
$$\nu_0(B_0) = \frac{\rho_n \sqrt{B_0} J_c(B_0)}{\sqrt{\Phi_0} B_{c2}}$$ Depinning frequency

$$Z_{sf} \equiv Z_f = Z_n \sqrt{\frac{B_0}{B_{c2}}} \quad \text{for } \nu \gg \nu_0,$$

$$R_{sf} \equiv R_f = \frac{R_n}{\sqrt{2}} \sqrt{\frac{B_0}{B_{c2}}} \left(\frac{\nu}{\nu_0}\right)^{3/2}, \quad R_n = \sqrt{\mu_0 \rho_n \pi \nu}$$

$$X_{sf} \equiv X_f = R_n \sqrt{2} \sqrt{\frac{B_0}{B_{c2}}} \left(\frac{\nu}{\nu_0}\right)^{1/2} \quad \text{for } \nu \ll \nu_0.$$

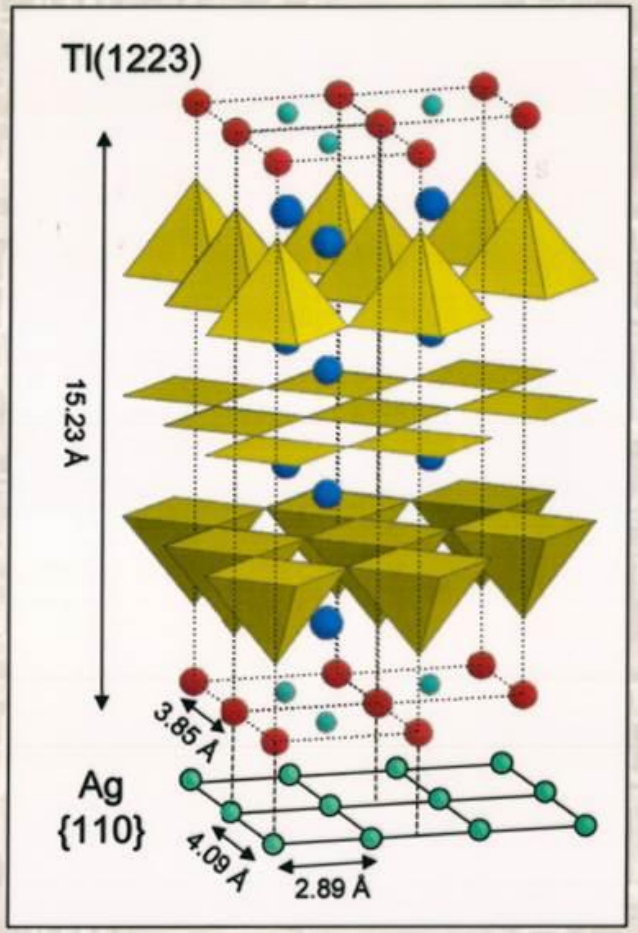
Assuming:
(conservative estimate)
ρ_n = 40 $\mu\Omega$ cm
B_{c2} (50K) = 70T.
$J_c \div 10^8$ to 10^9 A/m^2



At low frequencies, where the most unstable modes are predicted for a copper beam screen, a substantial gain of several orders of magnitude is clearly apparent

S. Calatroni, E. Bellingeri, C. Ferdeghini, M. Putti, R. Vaglio, T. Baumgartner and M. Eisterer, 2017 SUST **30** 075002

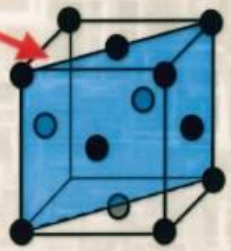
Electrodeposition



Lattice parameter matching of Tl(1223) and silver

The Ag{110} :

{110} plane



Initial Ag

Cold Rolling
20% reduction at each pass

Recrystallization
Vacuum 800 °C

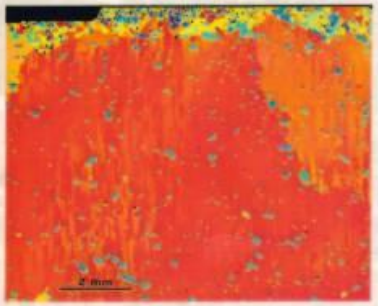
{110} textured ribbons

Bridgman technique

Orienting by X-ray
Laue method

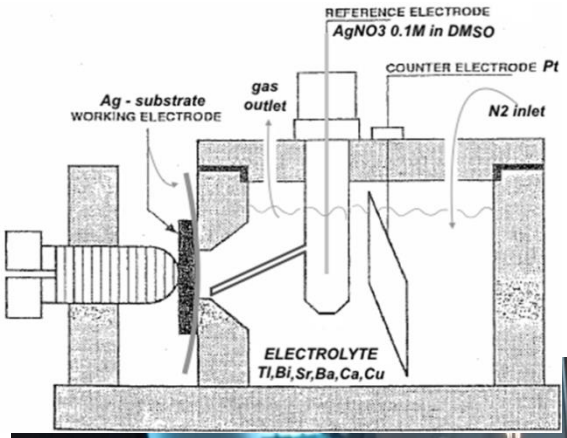
cutting
(electroerosion)
polishing and chemical etching

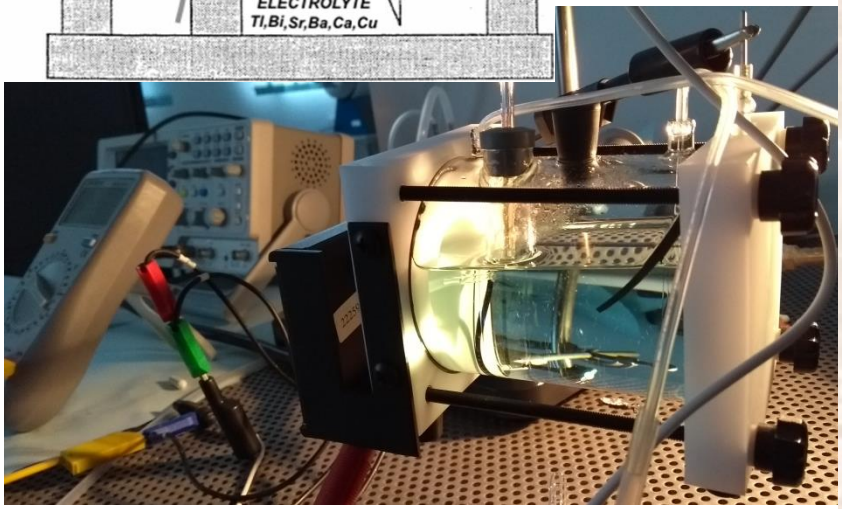
{110} Single crystal

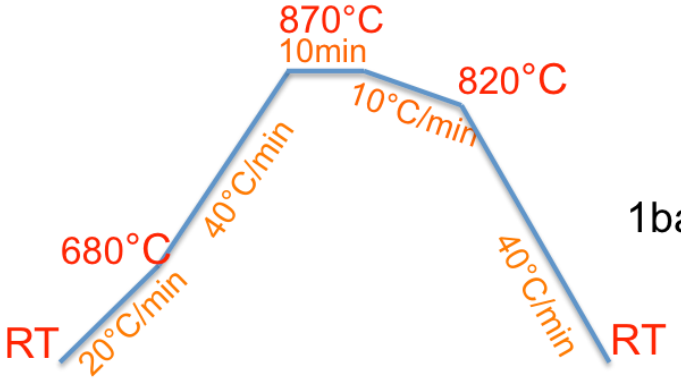


0 5 10°

Electron Back Scattered Diffraction map (EBSD)







1bar / 5.0 O_2

Solution:

Tl, Bi, Pb, Sr, Ba, Ca, Cu nitrates dissolved in DMSO

7 Elements !

Substrates :

Ag standard foils

Ag textured tapes

Ag single crystal

Vacuum annealing at 900 °C

$SrTiO_3$ single crystal

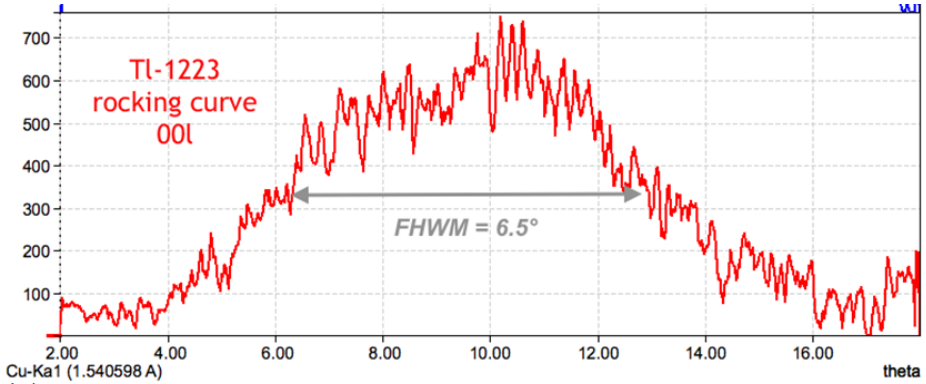
Chemical electrodeposition
1-10 min , -3 V (continuous)
1-20 min -3V , 10 s ; -1 V ,5 s (pulsed)

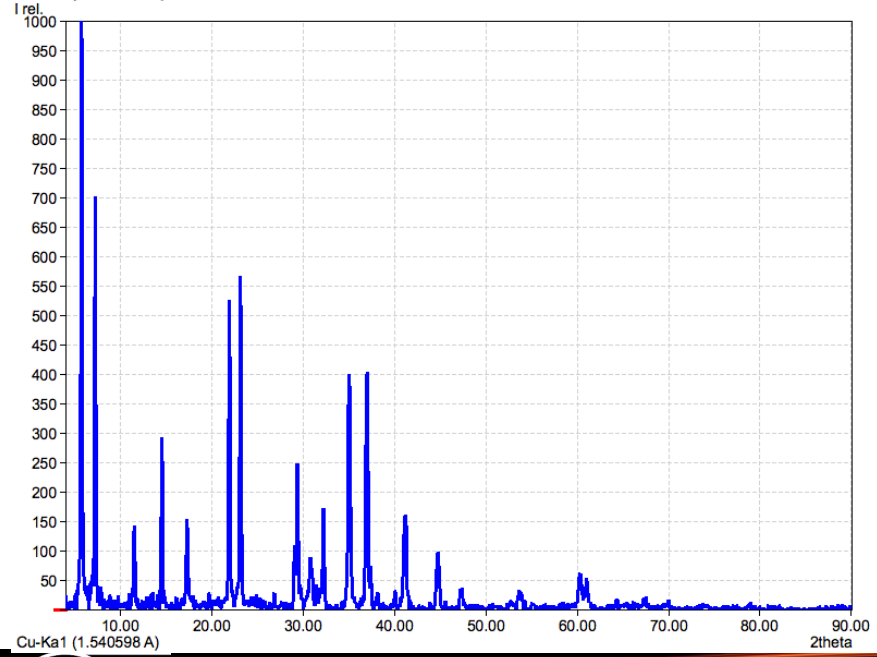
Oxidation reaction
~~High isostatic pressure (50 bar He~~/1 bar O_2)
870-930 °C 20-60 min

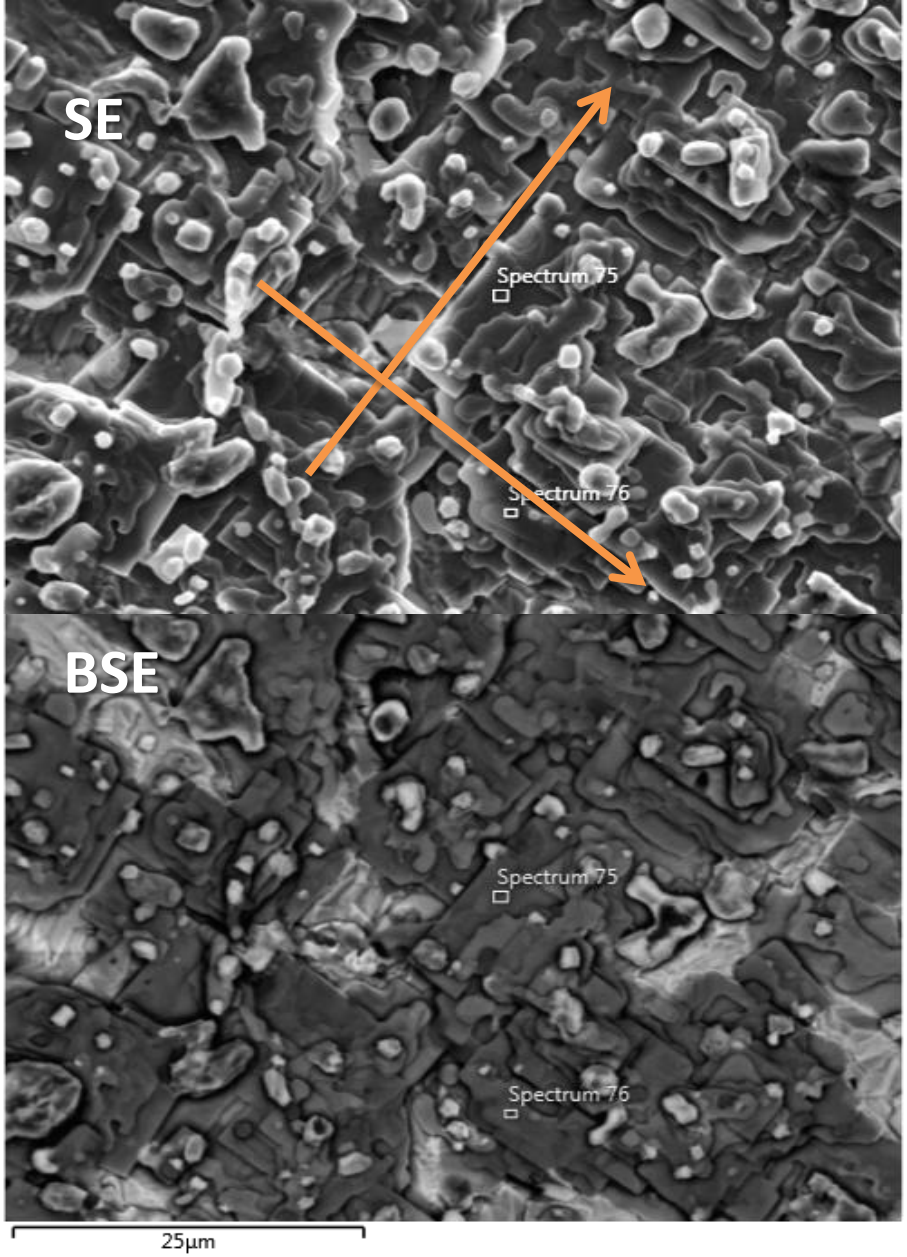
As rolled Ag ribbon

c axis texture

on Ag grain local epitaxy







For first preliminar superconducting characterization see 4MP5-16 S. Holleis et al. tomorrow morning.

Conclusions

- An HTSC coating have been proposed to mitigate the beam impedance in FCC
- Working condition are «Extreme»
- Models validate the feasibility with Tl(1223) and Re-123 (large gain at low frequency)
- A scalable deposition method for Tl(1223) based on electroplating was developed
- First S/C have been produced with local biaxial texture

To be done:

- Investigation of grain boundaries requirements
- Silver substrate optimization
- High-frequency, high field surface-resistance measurements (model validation)
- Secondary electron emission


THANK YOU FOR YOUR ATTENTION
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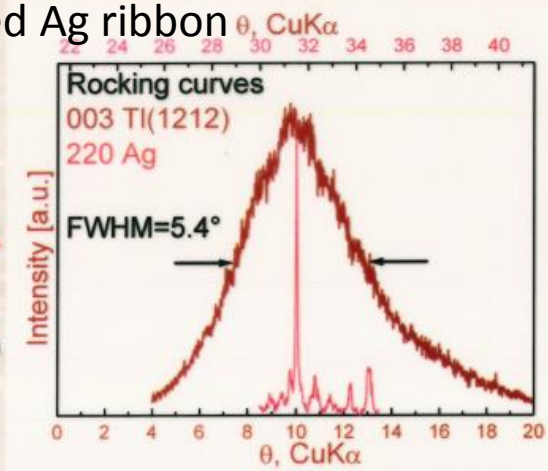
Electrodeposition on:

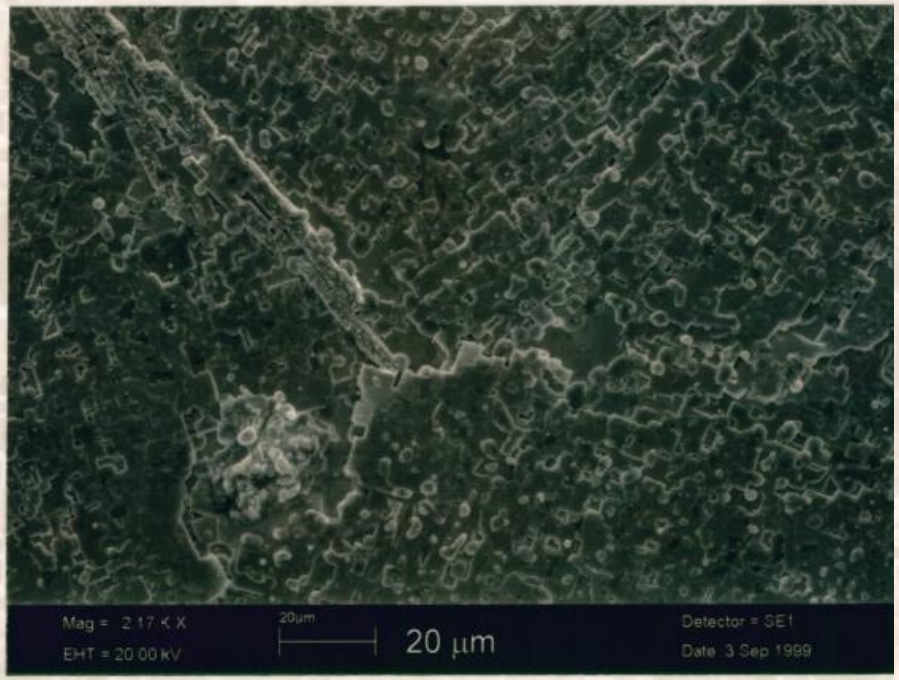
110 Textured Ag ribbon

Tl-superconductors grow epitaxially on the Ag: local biaxial texture.

The different Ag grains are rotated in the plane

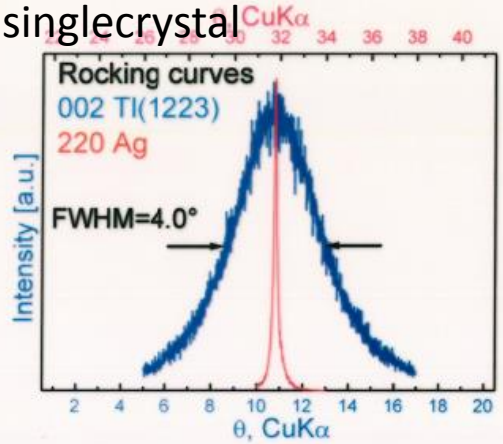
No macroscopic texture is present.

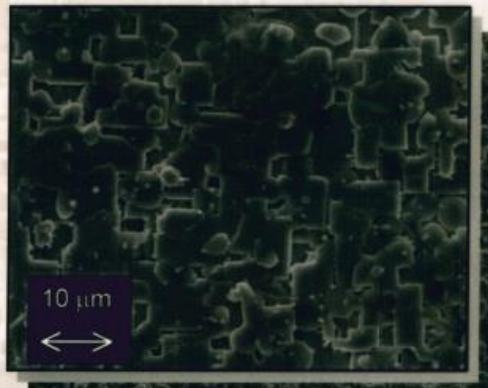


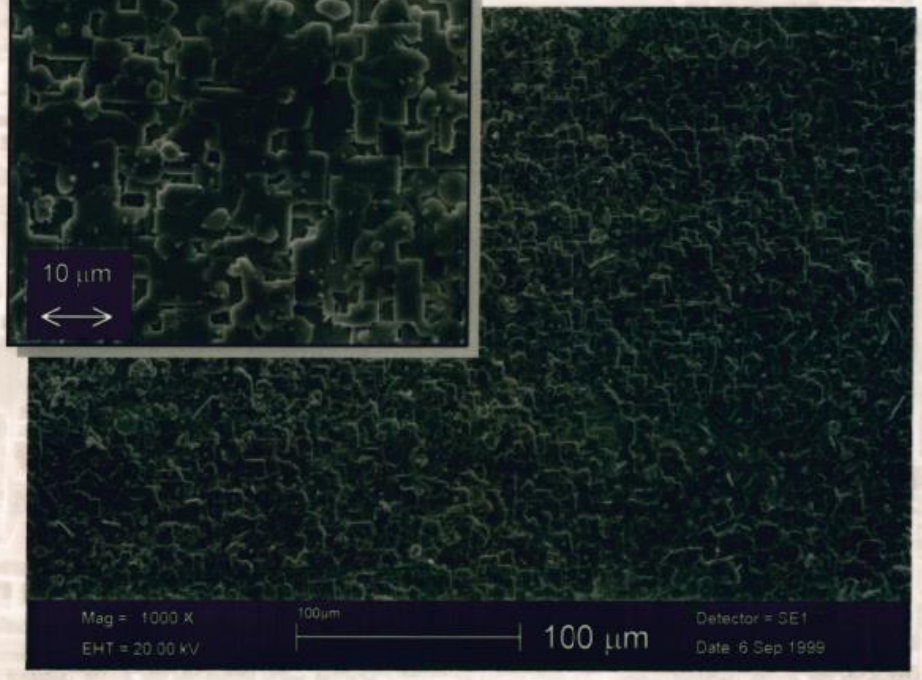


110 oriented Ag singlecrystal

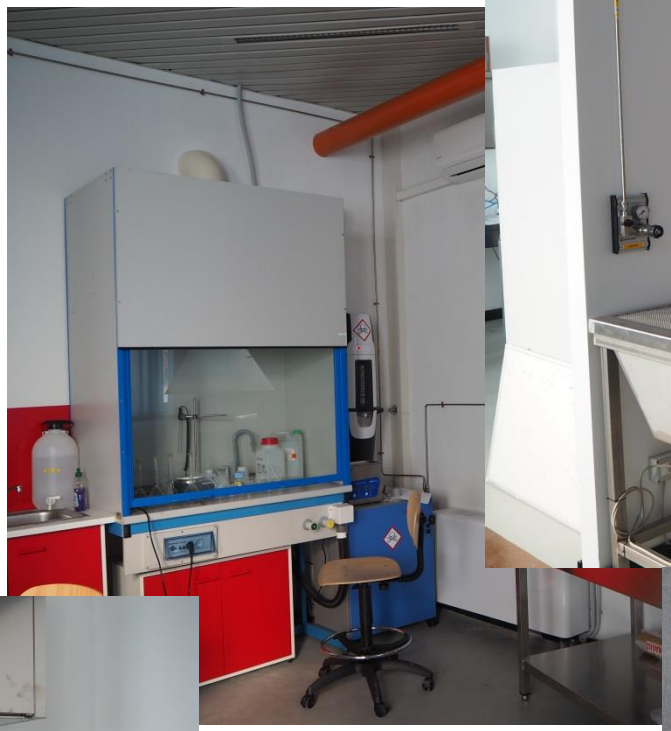
The biaxial alignement is observed in large region (>10 mm²).



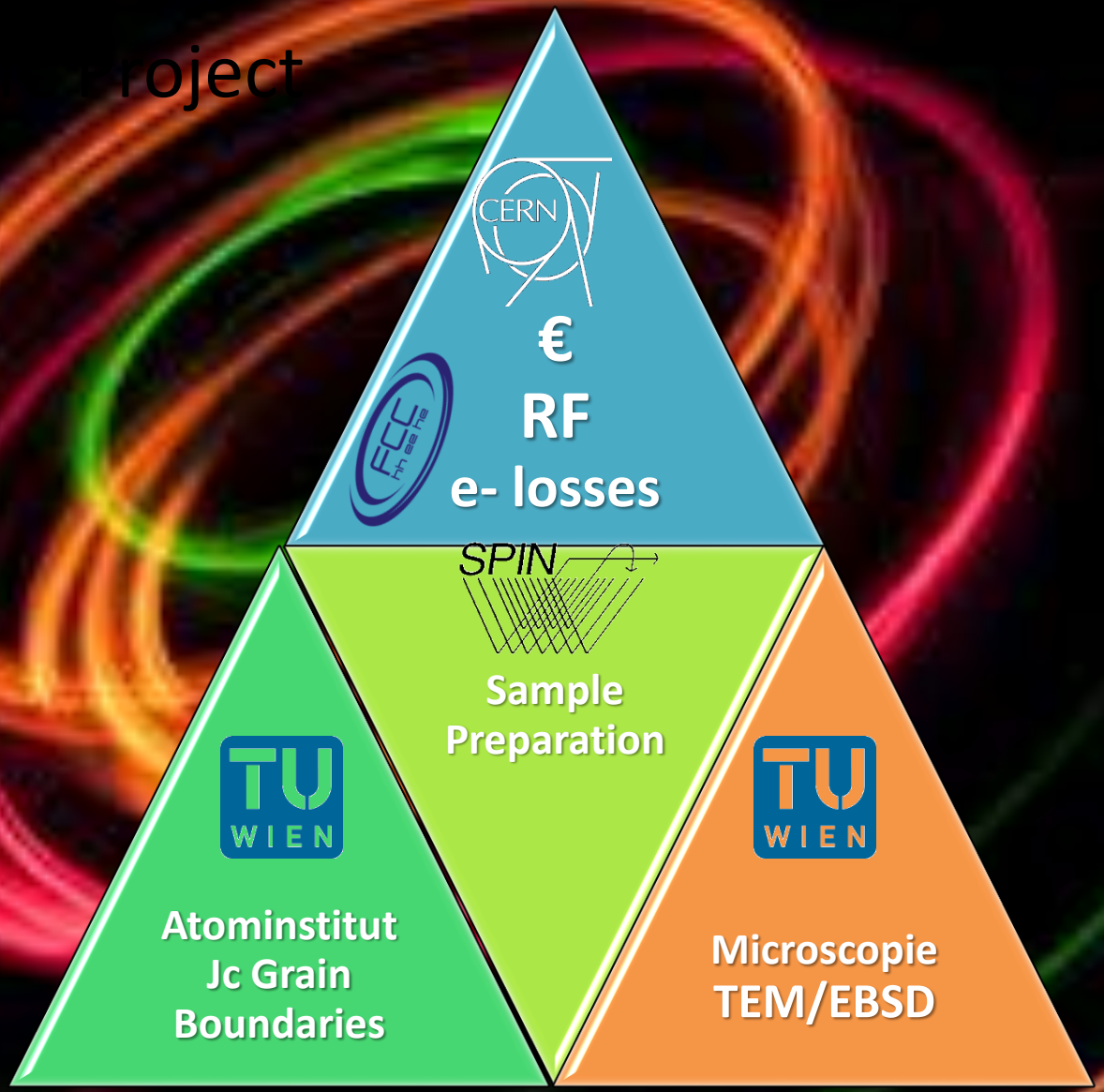




Thallium is toxic!
A new lab for safe manipulation of azardeous material have been realized



Project


CERN
€
RF
e- losses
SPIN
Sample
Preparation
TU WIEN
Atominstitut
Jc Grain
Boundaries
TU WIEN
Microscopie
TEM/EBSD