CERN

FCC-hh beam impedance mitigation at injection: Status report on HTS coating study

Sergio Calatroni - CERN

Synchrotron radiation/beam screen

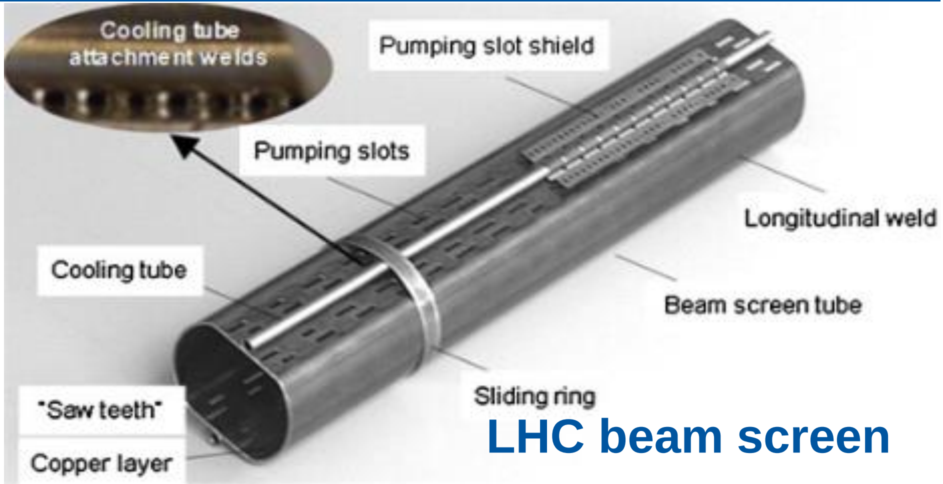
High synchrotron radiation load (SR) of protons @ 50 TeV:

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

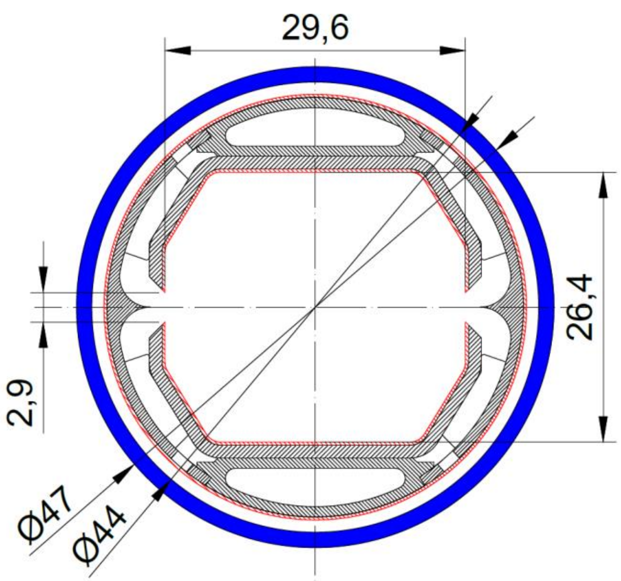
→ **5 MW total in arcs** (LHC <0.2W/m)

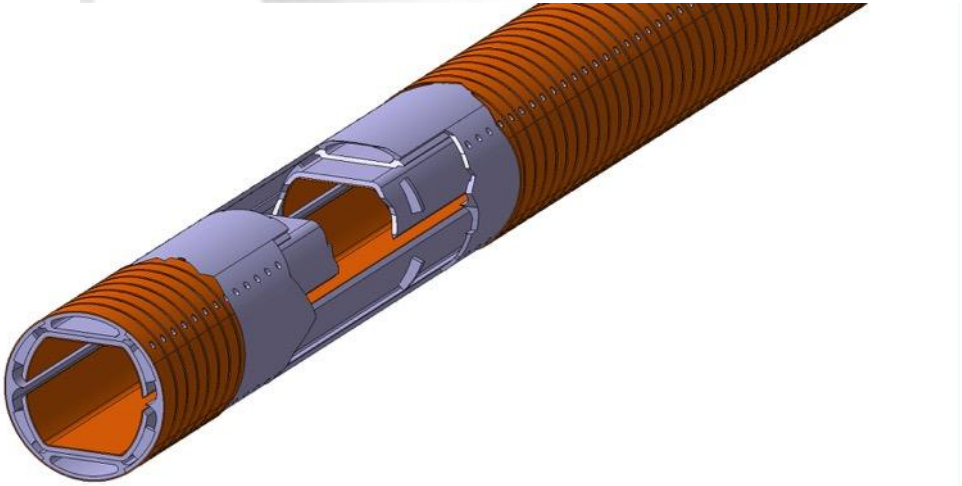
New type of ante-chamber

- absorption of synchrotron radiation
- avoids photo-electrons, helps vacuum



LHC beam screen



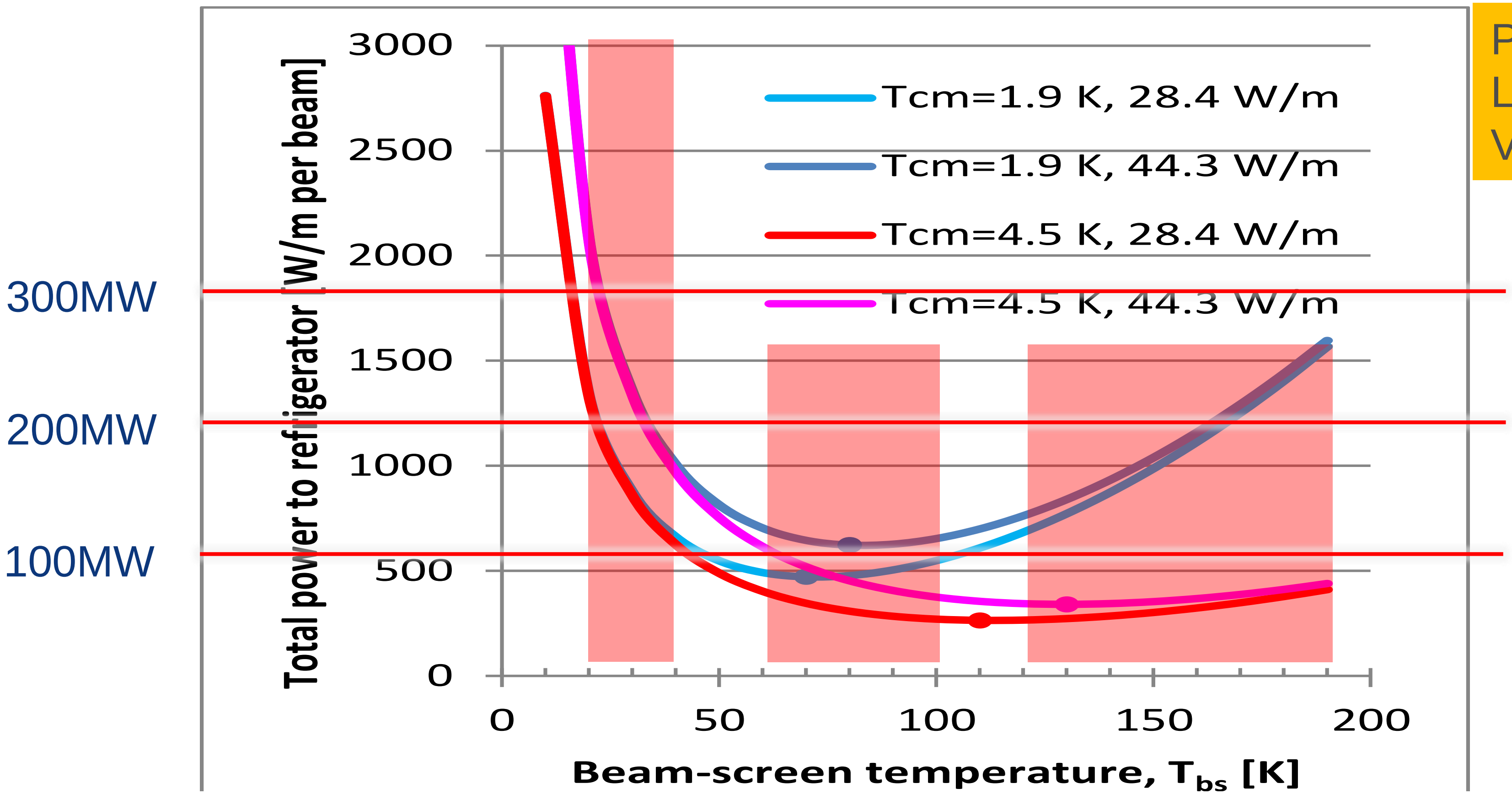


Courtesy: C. Garion

Cryo power for cooling of SR heat

Overall optimisation of cryo-power, vacuum and impedance
Termperature ranges: <20, 40K-60K, 100K-120K

Ph. Lebrun
L. Tavian
V. Baglin

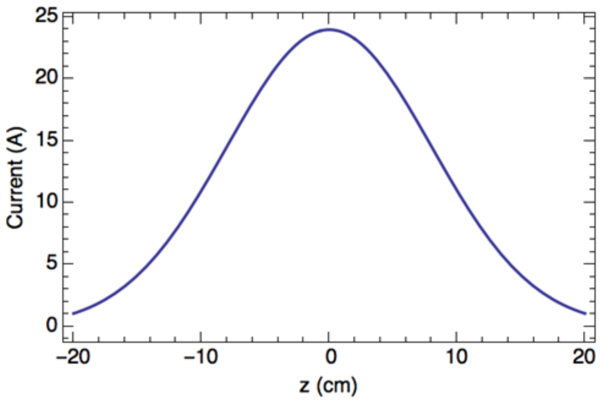


Refer to yesterday's presentation by O. Boine-Frankenheim for details on impedance estimates

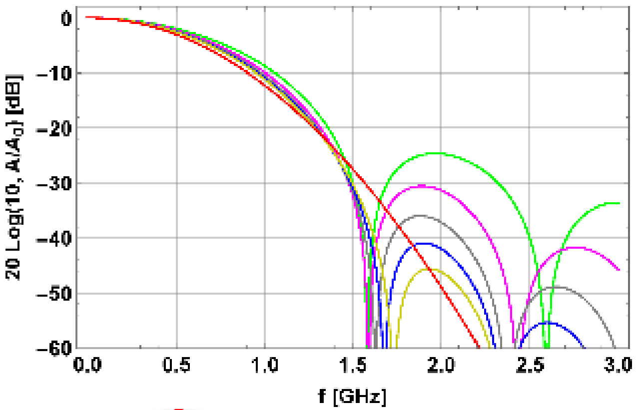
HTS films requirements for beam screen

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

Beam instantaneous image current



Frequency spectrum for various bunch shapes



Beam screen of ~30mm diameter.

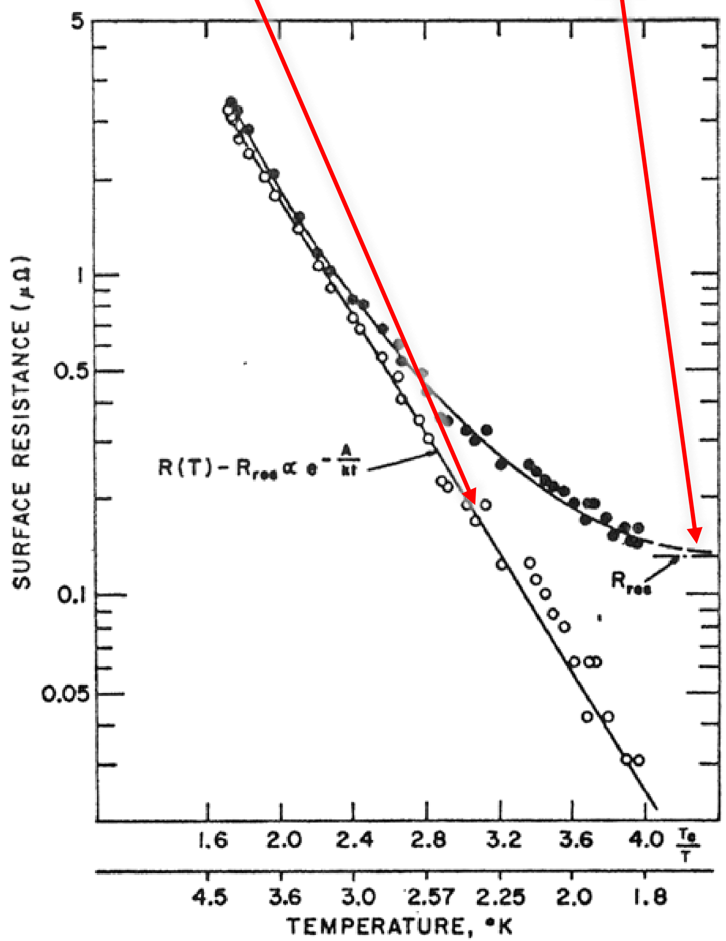
Assuming a film thickness / skin depth of 1 µm the HTS material should have a critical current density

Jc of about 25 kA/cm² (2.5x10⁸ A/m²) at 50 K and 16T

A superconductor in RF has non-zero surface resistance

- General definition

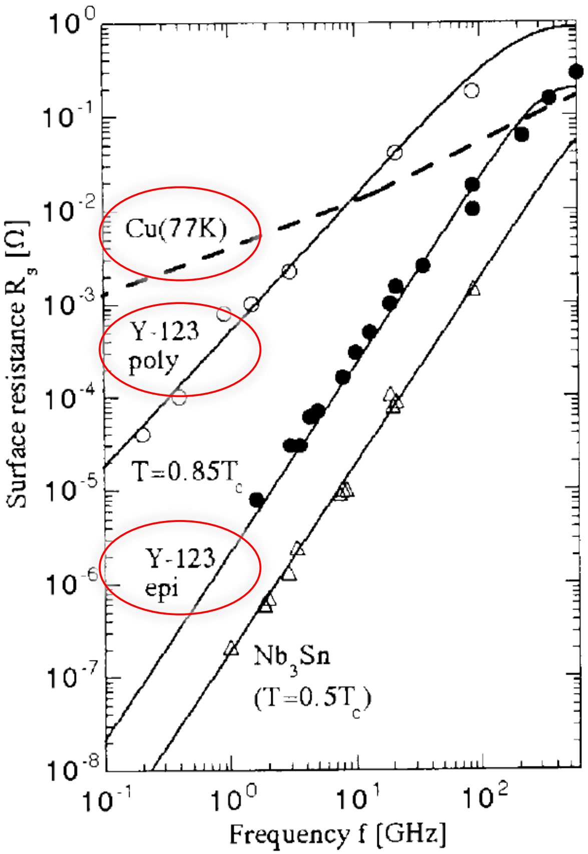
$$R_s(H_{rf}, T, B) = R_{BCS}(H_{rf}, T, 0) + R_{res}(H_{rf}, 0, 0) + R_{fl}(H_{rf}, T, B)$$



Expected performance

- Using YBCO as model, 77 K
- R_{BCS} and R_{res}, at zero H_{rf} and zero B_{ext}

HTS can have surface resistance lower than Cu at T< 77 K and 0 T f < 10 GHz



M. Hein, "High-Temperature Superconductor Thin Films at Microwave Frequencies", Springer

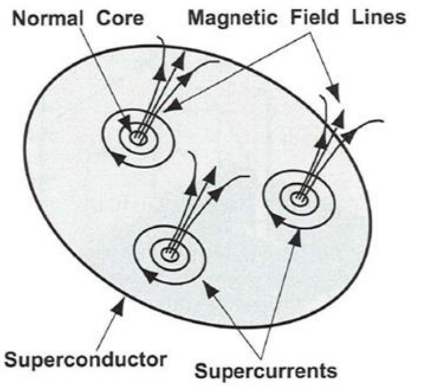
Surface resistance: effect of magnetic flux

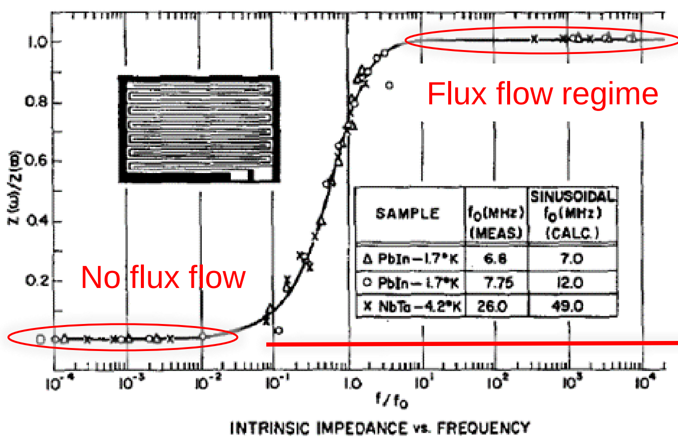
$$R_s(H_{rf}, T, B) = R_{BCS}(H_{rf}, T, 0) + R_{res}(H_{rf}, 0, 0) + R_{fl}(H_{rf}, T, B)$$

$$Z_{fl} = R_n \frac{B}{B_{c2}} \frac{\omega}{\omega^2 + \omega_0^2}(\omega + i\omega_0)$$

$\omega_0 \rightarrow$ Depinning frequency 1÷100 GHz

Harmonic damped oscillator: Flux flow depends on pinning strength and frequency





$$\omega \gg \omega_0 \rightarrow R_{fl} = R_n \frac{B}{B_{c2}}$$

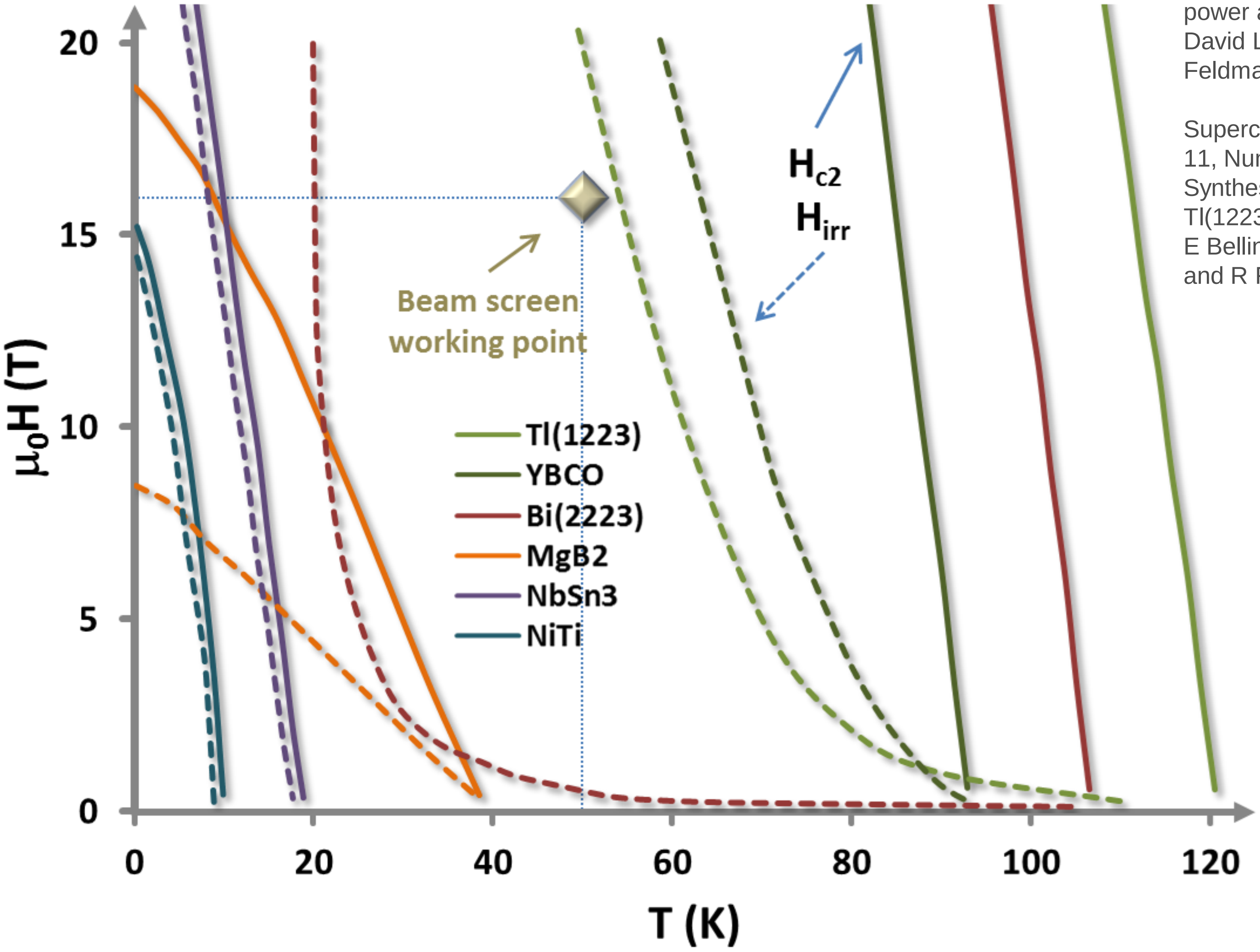
$$\omega \ll \omega_0 \rightarrow R_{fl} = R_n \frac{B}{B_{c2}} \frac{\omega^2}{\omega_0^2}$$

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

$$\frac{B}{B_{c2}} = \frac{16\ T}{80\ T} = 0.2$$

HTS in the normal state is “transparent” to RF
The NC skin depth is >> film thickness
What value for R_n ? HTS or copper?

Material choices



Data from:

Nature 414, 368-377 (15 November 2001)
High-Tc superconducting materials for electric power applications
David Larbalestier, Alex Gurevich, D. Matthew Feldmann & Anatoly Polyanskii

Superconductor Science and Technology, Volume 11, Number 8
Synthesis and properties of fluorine-doped Tl(1223): bulk materials and Ag-sheathed tapes
E Bellingeri, R E Gladyshevskii, F Marti, M Dhallé and R Flükiger

Courtesy: E. Bellingeri

Comparison table

	YBCO	Tl1223
PROs	• Safe • Very high Jc • Very high steep Hirr	• High Tc • High Jc • High Hirr • Very tolerant for out stoichiometry • Ag substrate
CONs	• Strong weak link problems • Low Tc • Very expensive and complex preparation on large scale (IBAD,..) • VERY SENSITIVE TO STOICHIMETRY • Substrate	• Toxic • Weak link?

Courtesy: E. Bellingeri

Challenges for HTS coatings

- YBCO and Tl-based HTS are the only possible candidates

- How to obtain good quality HTS inside tube geometry
  - Considerable experience exists in coated tape production for YBCO, scalability to tubes is extremely challenging

  - Tl-based HTS has characteristics similar to YBCO, and should allow full scalability to tubes thanks to electrodeposition on silver (coated) substrates

- Need to measure RF performance as a function of T, B, J at frequencies relevant for FCC (< 1 GHz)

Collaboration on Tl-based HTS

- CERN has started a Collaboration with CNR-SPIN and TU-Vienna in the frame of the FCC to develop Tl-based coatings

- Scope of the collaboration is focussed on the beam screen

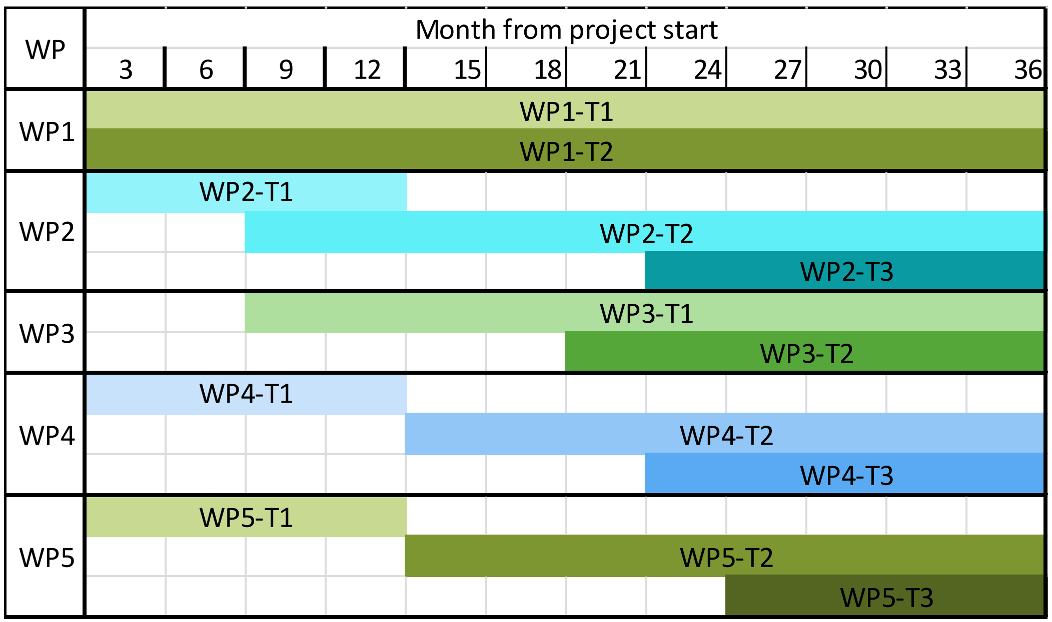
- FCC frame allows for fundamental R&D on materials with possible outcomes outside the primary goal (e.g. coated conductors for magnets)

- See poster by Emilio Bellingeri et al. for further scientific and technical details

Collaboration work plan

The work to be done is subdivided into five packages (WPs) over three years

- WP1: Management (CERN)
- WP2 : Development of textured Tl-based materials (CNR-SPIN)
- WP3 : Micro-structural analysis (TUW-USTEM)
- WP4 : Characterization of superconducting properties (TUW-ATI)
- WP5 : Accelerator environment compatibility (CERN)



WP1
- T1: Administration
- T2: Scientific co-ordination

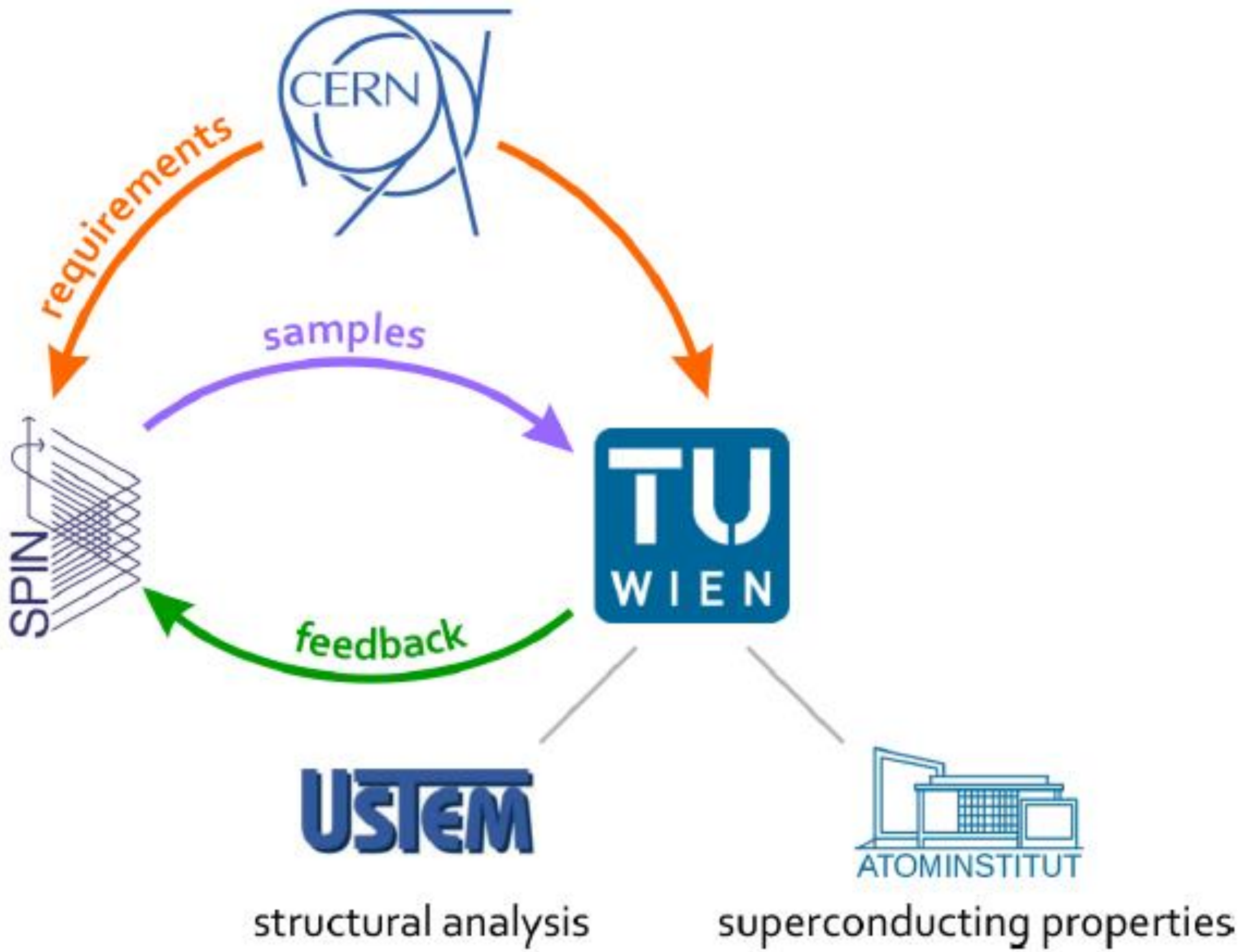
WP2
- T1: Laboratory implementation
- T2: Precursor materials & polycristalline films
- T3: Production route for Tl-based coatings

WP3
- T1: Polycrystalline Tl-1223/1212 films
- T2: textured Tl-based coatings

WP4
- T1:Scanning probe system set up
- T2: Local field mapping
- T3: Current transport across GB

WP5
- T1: Evaluation of neutron irradiation spectrum
- T2: UHV compatibility
- T3: Evaluation of persistent currents

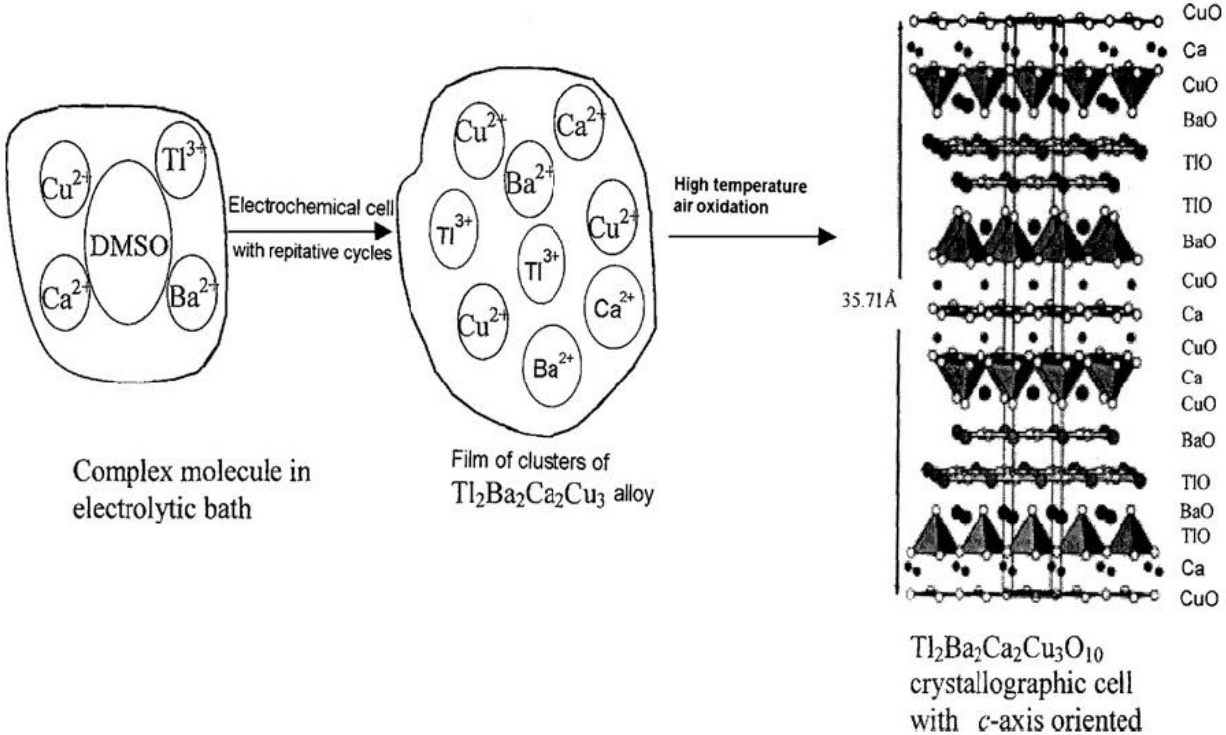
Collaboration workflow



Courtesy: T. Baumgartner

WP highlights (future work)

- WP2 (CNR-SPIN): explore precursors preparation, produce policrystalline films and identify suitable production route for thick Tl-HTS films



The schematic of the different steps involved in electrochemical processing of Tl–Ba–Ca–Cu–O superconductor film.

Courtesy: E. Bellingeri

WP highlights (future work)

- WP3 (TUW-USTEM): structural properties of poly- and epi- films

Key issues

- Correlation manufacturing / processing conditions – microstructure - sc properties: SEM, TEM, HRTEM
- Texture analysis: EBSD, TKD, SAD
- Grains, grain boundaries, chemical homogeneity: EDX, EELS, TEM, SEM (STEM)
- Defect analysis: TEM, SEM (ECCI, EBSD)
- Radiation experiments: sample preparation and handling

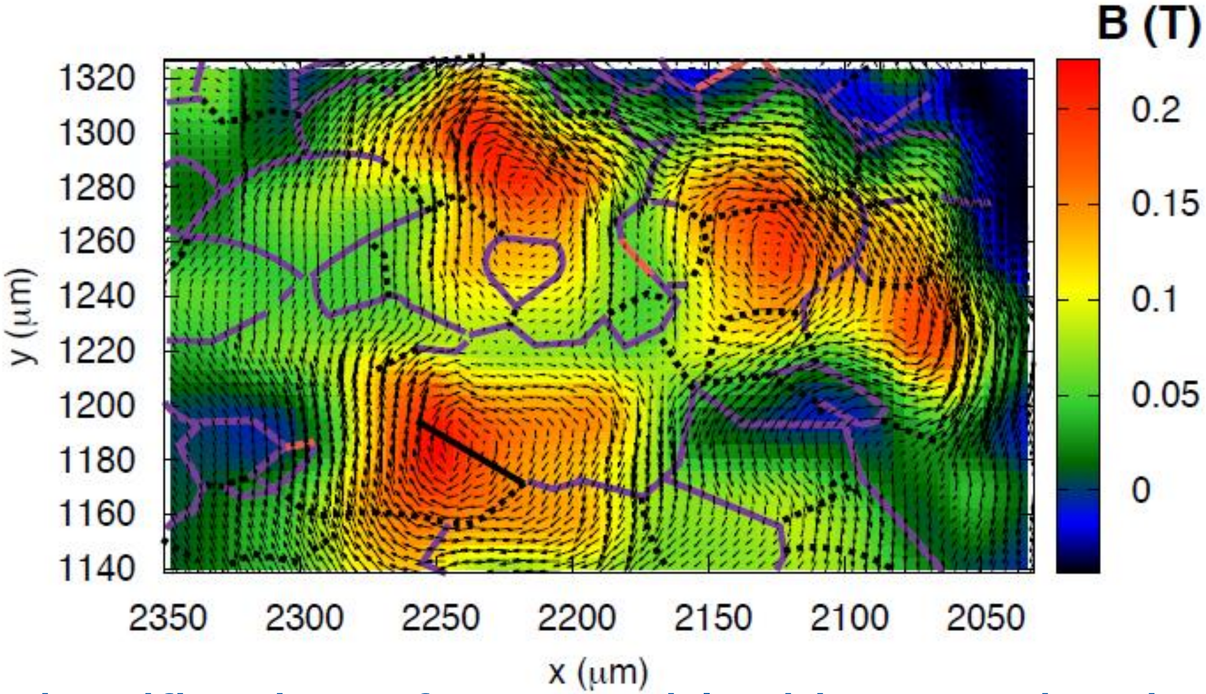
USTEM

Courtesy: J. Bernardi

WP highlights (future work)

- WP4 (TUW-ATI): global and local superconducting transport properties of Tl-coatings

e.g. field map above thin film, correlation with grain and grain boundary structure.



Identification of current blocking mechanisms

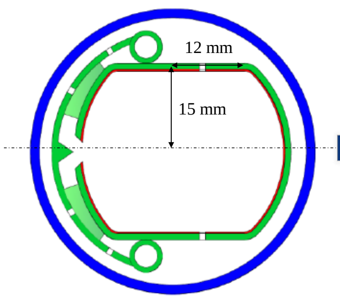
Courtesy: M. Eisterer

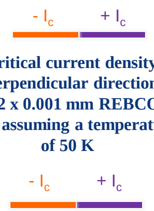
WP highlights (future work)

- WP5 (CERN) compatibility with accelerator environment: vacuum, SEY, RP hazards, persistent currents

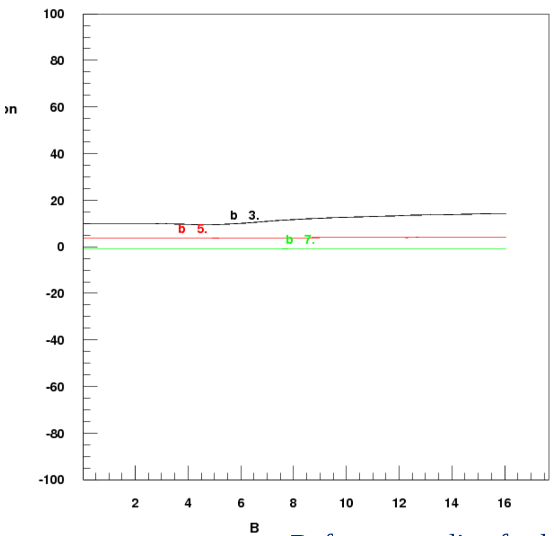
Impact on field quality

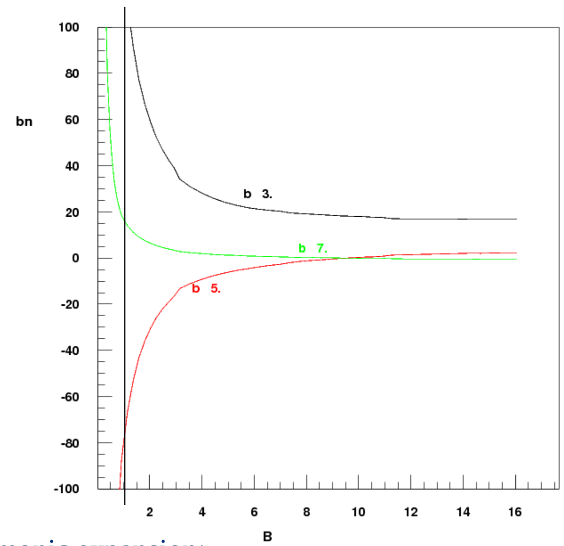
- Very large impact on the field quality at low current
- It will be critical, as at injection (~1T), harmonics should be within 10 units





I_c = critical current density in the perpendicular direction in a 12 x 0.001 mm REBCO layer, assuming a temperature of 50 K





Reference radius for harmonic expansion: R_{ref}=16.7 mm (2/3 of the magnet aperture)

6

Courtesy: S. Izquierdo Bermudez

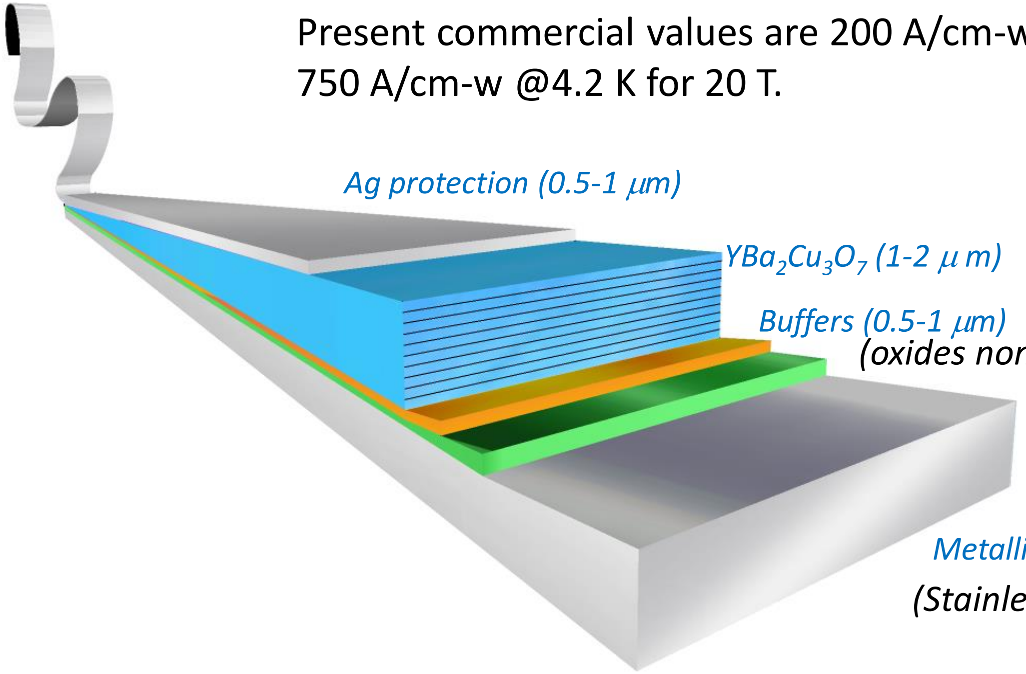
What about YBCO

CSIC ICMAB

What is a Coated Conductors (CC) ?

CC is a long length (km) epitaxial YBCO films on a flexible metallic substrate capable of carrying large currents

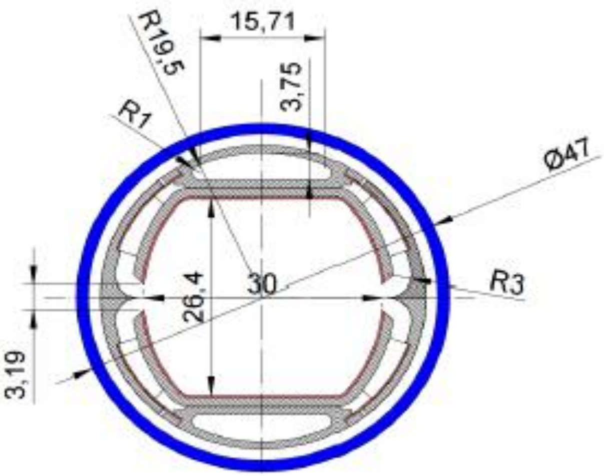
Present commercial values are 200 A/cm-width @77 K and 750 A/cm-w @4.2 K for 20 T.



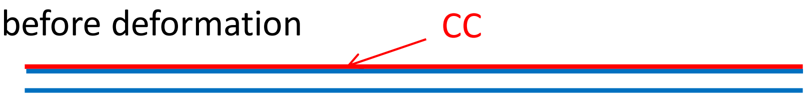
Courtesy: T. Puig

Barcelona proposal

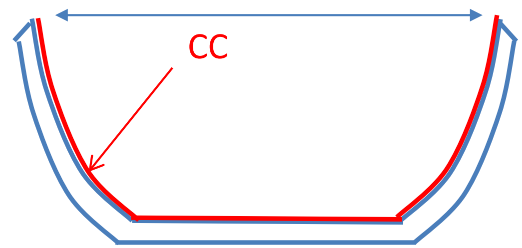
Collaborative proposal



1.- Use wide CC and solder a single piece on the steel plate before deformation

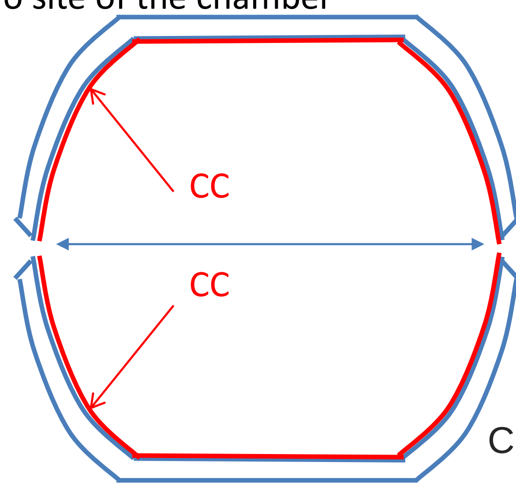


2.- Shape the ensemble



Schematic drawing not at scale

3.- Ensemble the two site of the chamber



The two inner pieces of the chamber can be covered by the CC before assembling

Simulations of 1μm YBCO layer have shown the benefit of superconducting surface impedance reduction at RF

S. Calatroni, IEEETransSuprcond. (submit.)

Courtesy: T. Puig, F. Perez

Open questions

- RF characterization is needed in order to validate materials, deposition process and scaling to tubes.
- Ideally, RF characterization should be done on
  - Small size samples
  - Finished beam-screen sized “tubes”
- Novel challenge is performing RF characterization up to 16 T and in the range 4.5K – 120 K (or larger)

  - ➢ Will likely be addressed within the ALBA-ICMAB-IFAE collaboration

Outlook

- Strong motivation for HTS coatings for FCC beam screens, with potential of drastically reducing beam impedance.

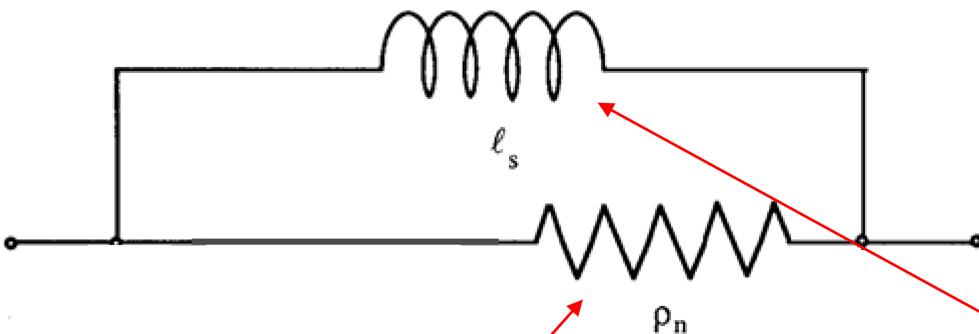
- Tl-1223:
  - promising performance, opens up >100 K temperature window
  - scalable coating -> focussed R&D with CNR-SPIN and TU-Vienna
- YBCO:
  - Proven performance
  - Challenging to coat inside beam screens, need forming technology -> proposal being worked out with ICMAB-ALBA-IFAE

- Coating properties need extensive experimental validation, for any specific coating process.

CERN

Surface resistance

- Surface resistance is the quantity we typically measure for superconducting accelerating RF cavities
- A superconductor in RF has non-zero resistance
- Two fluid model:



$$\sigma_s = \sigma_1 - i\sigma_2 = \sigma_n \left(T^4 / T_c^4 \right) - i \frac{\sigma_n}{\omega\tau} \left(1 - T^4 / T_c^4 \right)$$

Comparison: Y-123, Bi-2223, Tl-1223

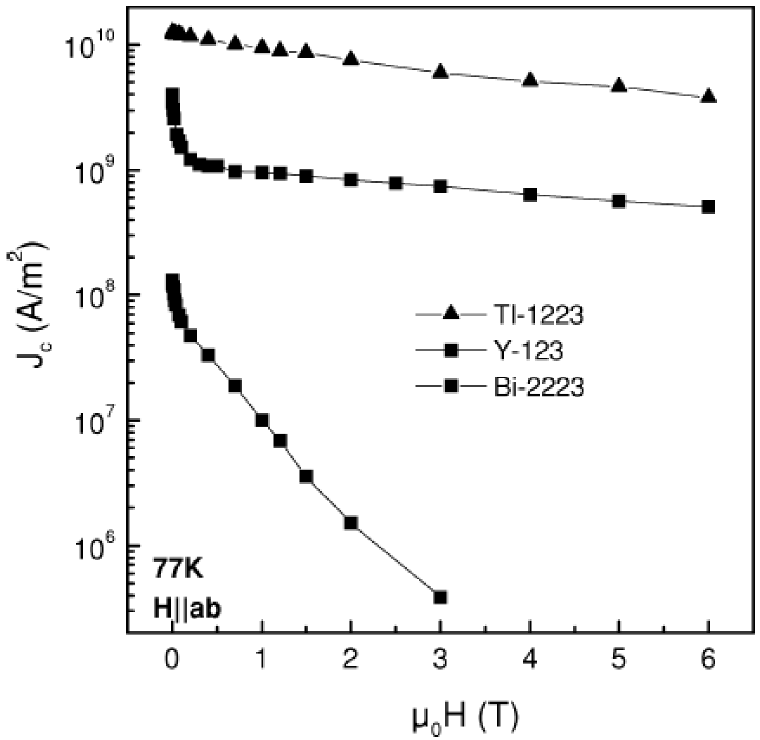


Fig. 1. J_c versus field at 77 K and $H \| ab$ for an Y-123 coated conductor, a Bi-2223 tape and a Tl-1223 thick film.

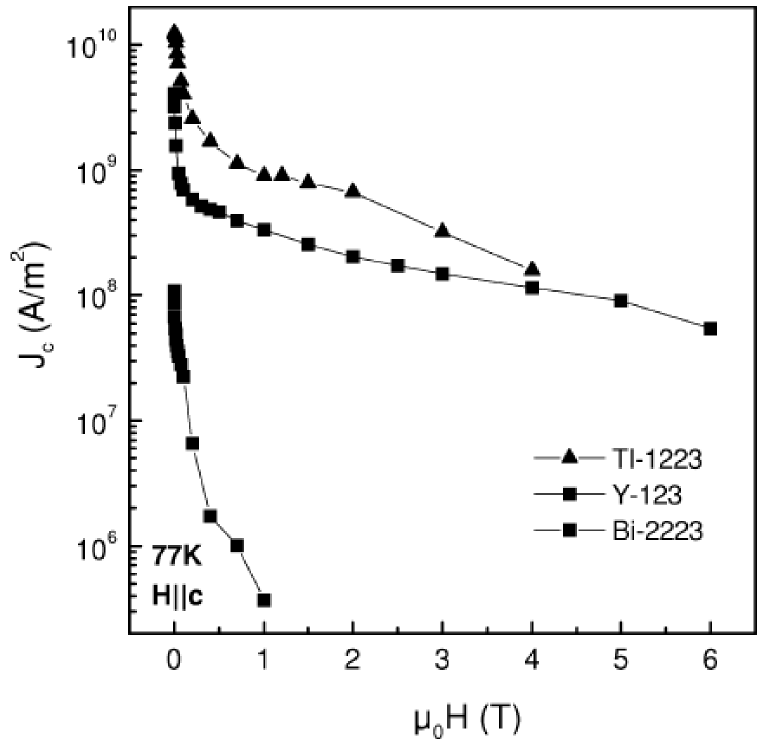
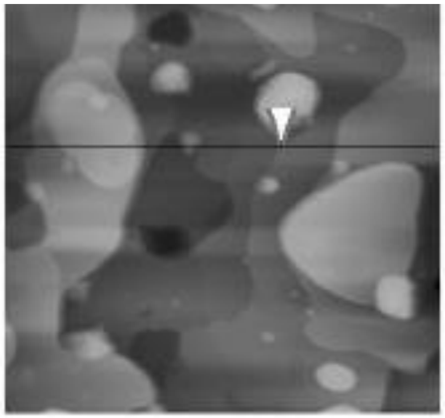


Fig. 2. J_c versus field at 77 K and $H \| c$ for an Y-123 coated conductor, a Bi-2223 tape and a Tl-1223 thick film.

Susanne Tönies, Harald W. Weber, Gerhard Gritzner, Oliver Heiml, and Mario H. Eder,
IEEE TRANSACTIONS ON APPLIED SUPERCONDUCTIVITY, VOL. 13, NO. 2, JUNE 2003

Preparation of Tl-2212 and Tl-1223 Superconductor Thin Films and Their Microwave Surface Resistance

A. Sundaresan, H. Asada, A. Crisan, J. C. Nie, H. Kito, A. Iyo, Y. Tanaka, M. Kusunoki, and S. Ohshima



***Abstract*—Epitaxial $Tl_2Ba_2CaCu_2O_y$ and $Tl(Ba,Sr)_2Ca_2Cu_3O_y$ thin films have been prepared on CeO_2 buffered sapphire substrate by an *ex situ* process with high reproducibility. Microstructure analysis of the surface of the Tl-2212 films showed well connected and smaller sized grains of 1 μm or less. In the case of Tl-1223 film, plate-like crystals with pits and pin holes could be observed. The superconducting critical temperatures of both films are around 96 K. Critical current density measured by ac susceptibility technique is as high as 1 MA/cm^2 at 77 K. The microwave surface resistance of these films was measured over a wide range of temperatures by a HTS-sapphire-HTS resonator method at 38 GHz on films with area 10 mm $\times$ 10 mm. The temperature dependence of surface resistance of Tl-2212 film follows very closely to that of the best YBCO films on MgO substrate, whereas the Tl-1223 exhibits slightly higher values resulting from an inferior surface morphology.**

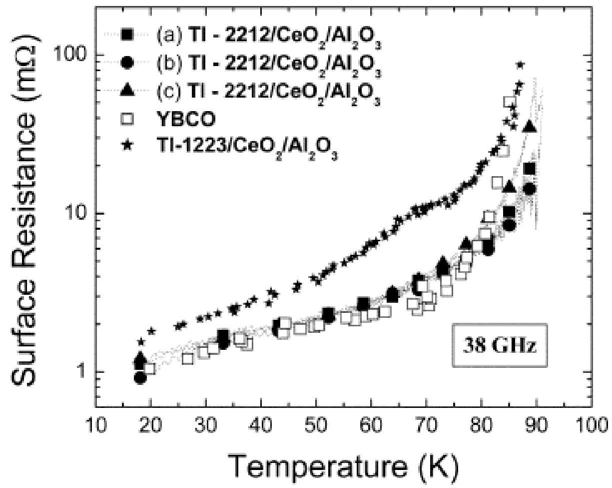


Fig. 5. Temperature dependence of microwave surface resistance of Tl-2212 and Tl-1223 films. The data of YBCO film is also shown for comparison.

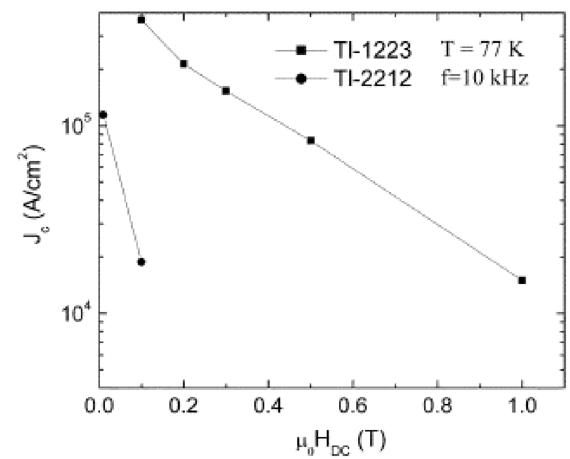


Fig. 4. Critical current density at various dc fields for Tl-2212 and Tl-1223 films determined from ac susceptibility measurements.