FCC WEEK 2019 -talk

BRUSSELS, BELGIUM
24 – 28 June 2019
Crowne Plaza Brussels
Le Palace

$REBa_2Cu_3O_7$ coated conductors as a beam screen coating: *Linking surface resistance to microstructure*

A.Romanov[1], J. Gutierrez[1] , P.Krkotic[2], J. O'Callaghan[3], F. Perez[2], M. Pont[2], X. Granados[1] , S. Calatroni[4], M. Taborelli[4] and T. Puig[1]

1 Institut de Ciència de Materials de Barcelona, CSIC, Bellaterra (Spain)
2 ALBA Synchrotron Light source, Cerdanyola del Vallés (Spain)
3 Universitat Politècnica de Catalunya, Barcelona (Spain)
4 CERN - The European Organization for Nuclear Research, Geneva (Switzerland)

26.06.2019

Outline

1. *REBCO CCs for beam screen coating*
2. *Linking CC´s surface resistance to microstructure*
3. *Evaluation of secondary electron yield*

1. Motivation: *REBCO CCs for beam screen coating*

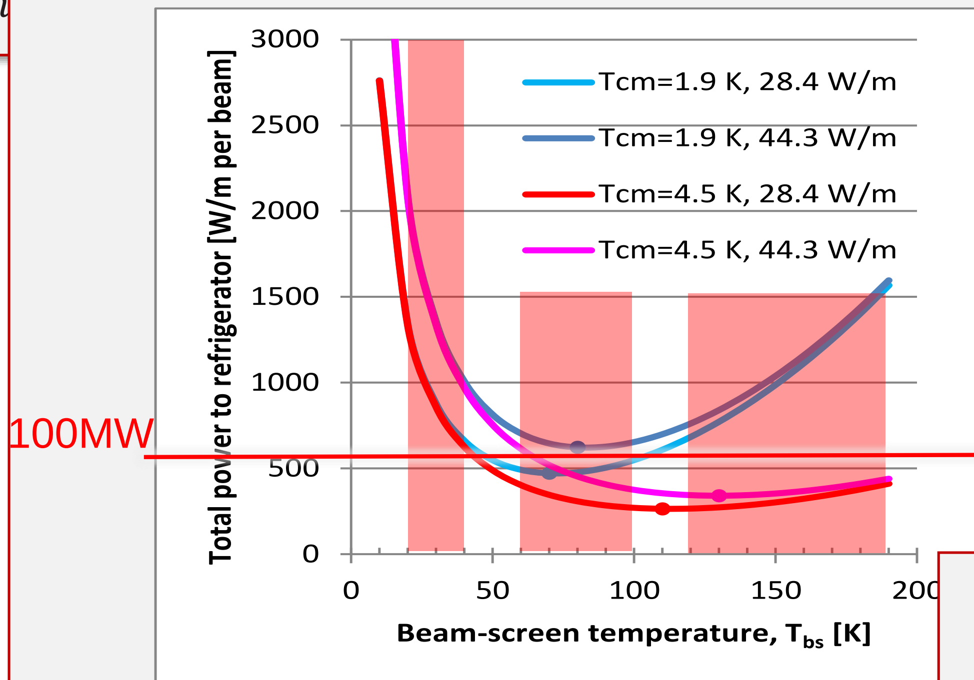
Synchrotron radiation in FCC much higher:

$P_{beam}^{LHC} \sim 0.2\ W/m$

$P_{beam}^{FCC} \sim 35.4\ W/m$

Cryogenic load

Limit the cryogenic load to 100 MW → $\Delta T_{FCC} = 40 - 60K$



Impacts T_{FCC}

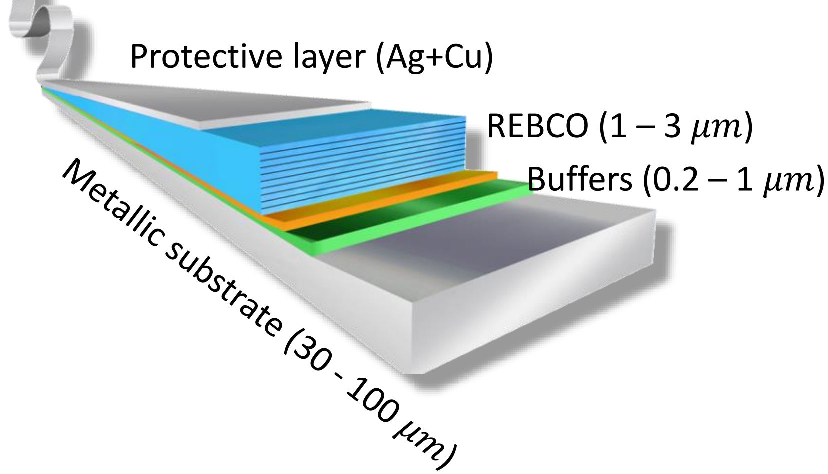
Cu may not provide low enough surface impedance at 40-60K

Superconductors belong to only material class where $R_s^{SC} < R_s^{Cu}$

1. Motivation: *REBCO CCs for beam screen coating*

REBCO coated conductors are layered structures consisting of:

- **Multifunctional oxides**
  - **HTS $REBa_2Cu_3O_{7-x}$**
  - **Buffers that allow epitaxial growth**
- **Flexible, metallic substrate**



Superconductive at FCC conditions:

$T_c \approx 93K$ $B_{c2}(50K) \approx 80T$ $I_c(50K, 16T) > 25A$

Commercially available in km length (≈5000 km/a).

Participating manufacturers in FCC study

SuNAM, BRUKER (Bruker HTS GmbH), SuperOx, Fujikura, THEVA, SuperPower Inc. (A Furukawa Company)

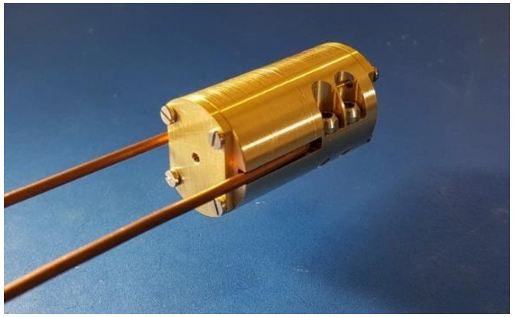
High customization through microstructure tailoring :

Rare earth	*Intrinsic PC*	*Artificial PC*
Y	Grain boundaries	$BaZrO_3$
Gd	Secondary phases	$BaHaO_3$
Eu	Stacking faults	…
Dy	Point defects	
…	…	

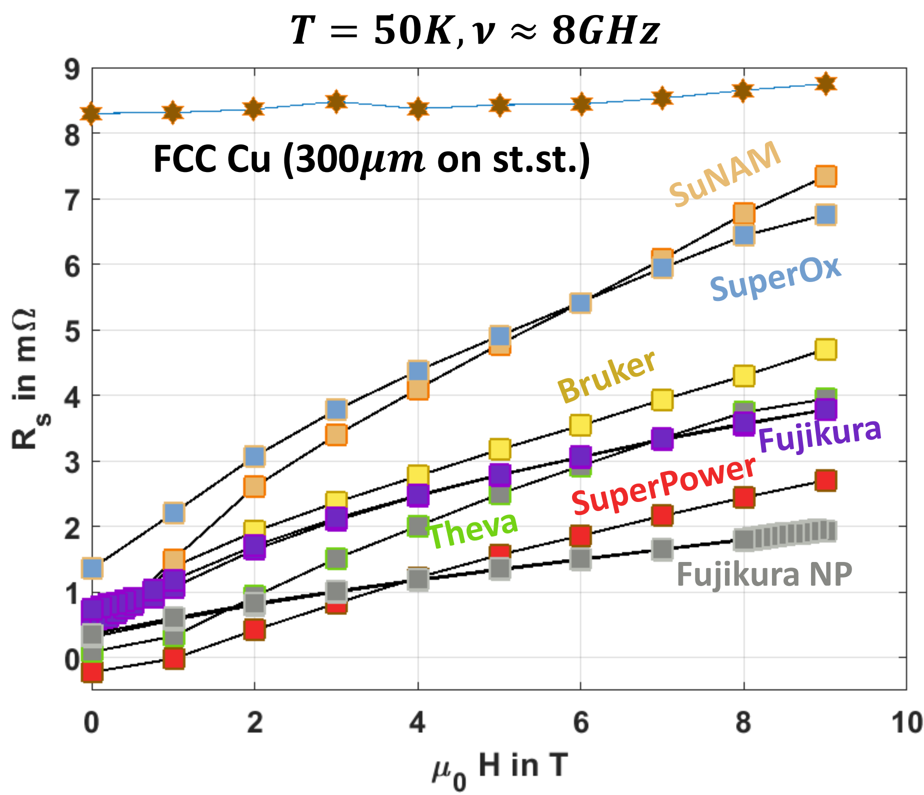
Outline

1. *REBCO CCs for beam screen coating*
2. ***Linking CC´s surface resistance to microstructure***
3. *Evaluation of secondary electron yield*

2. Linking R_s to microstructure



- Within the consortium, ALBA and UPC developed 8 GHz cavity dielectric resonator
- compatible with 25mm bore 9 T magnet at ICMAB

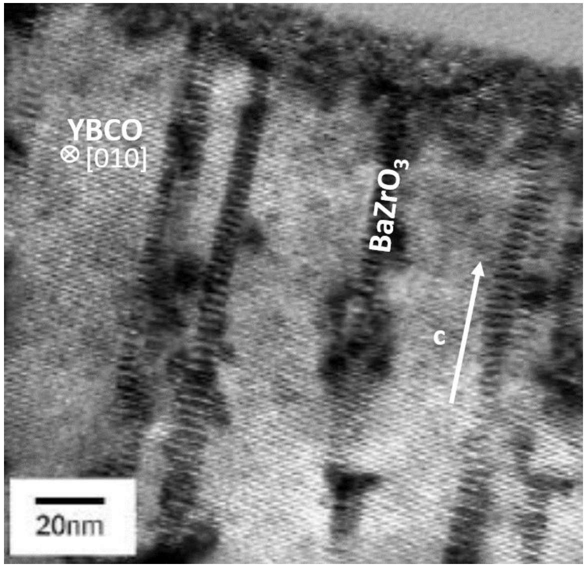


T. Puig et al. (SUST accepted)

State of the art REBCO CCs outperform Cu at 50K, 8 GHz and up to 9T

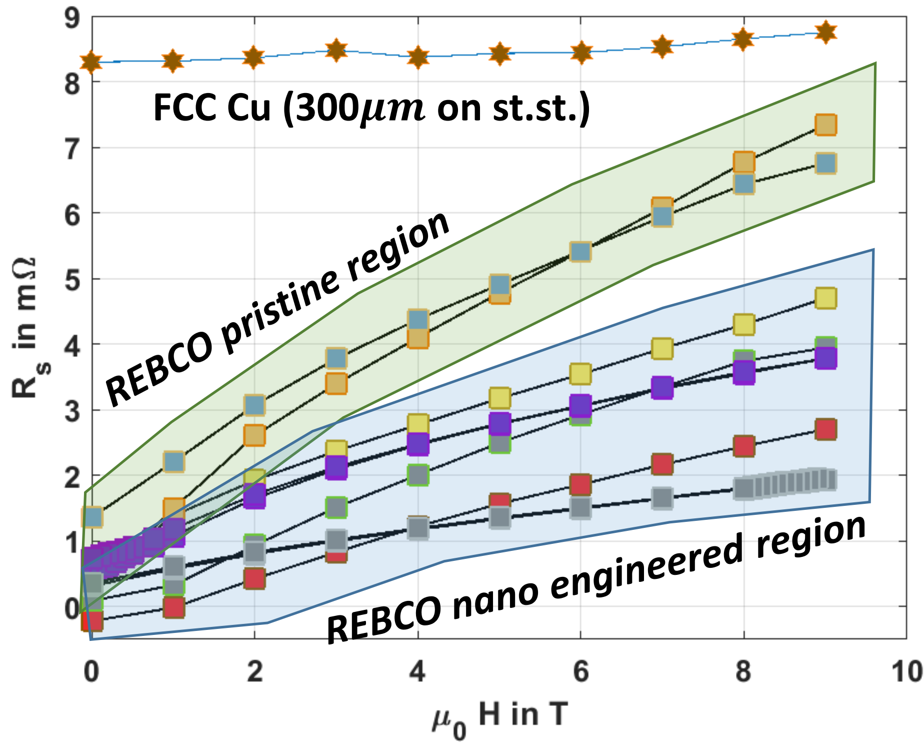
2. Linking R_s to microstructure

Microstructure of YBCO with BZO nanorods



S. Kang, Science 311 (2006)

$T = 50K, \nu \approx 8GHz$



T. Puig et al. (SUST accepted)

State of the art REBCO CCs outperform Cu at 50K, 8 GHz and up to 9T

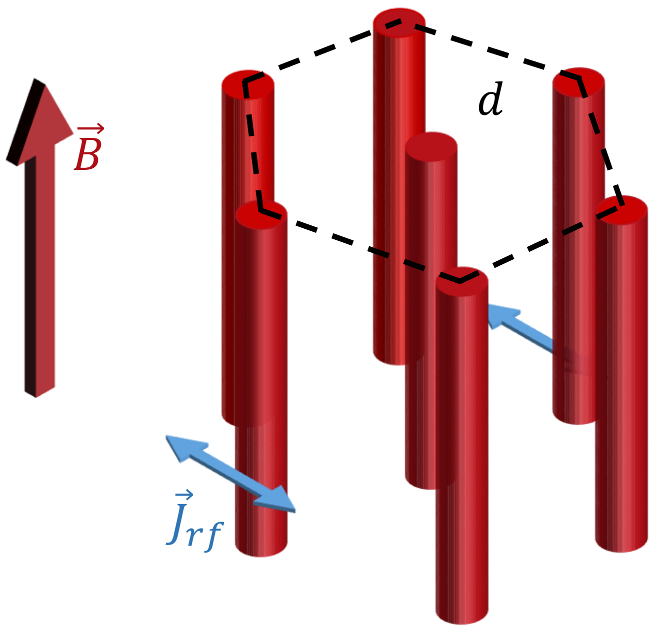
R_S is microstructure dependent

2. Linking R_s to microstructure

Classical rigid-fluxon model

S. Calatroni and R. Vaglio, IEEE Transactions on Applied Superconductivity 27, 2017

Flux tube lattice



<u>Assumptions:</u>

1. Fluxon shape cannot be deformed
2. Rigid flux tube lattice

Equation of motion for fluxons:

$$m\ddot{x} + \eta\,\dot{x} + kx = J_{rf}\Phi_0$$

Surface resistance:

$$R_{fl}(T,H,\nu) = R_n\sqrt{\sqrt{a^2(J_c,\rho,B_{c2}) + b^2(J_c,\rho,B_{c2})} - b(J_c,\rho,B_{c2})}$$

Depinning frequency:

$$\nu_0 = \rho_n \frac{J_c}{B_{c2}}\sqrt{\frac{H}{\phi_0}}$$

2. Linking R_s to microstructure

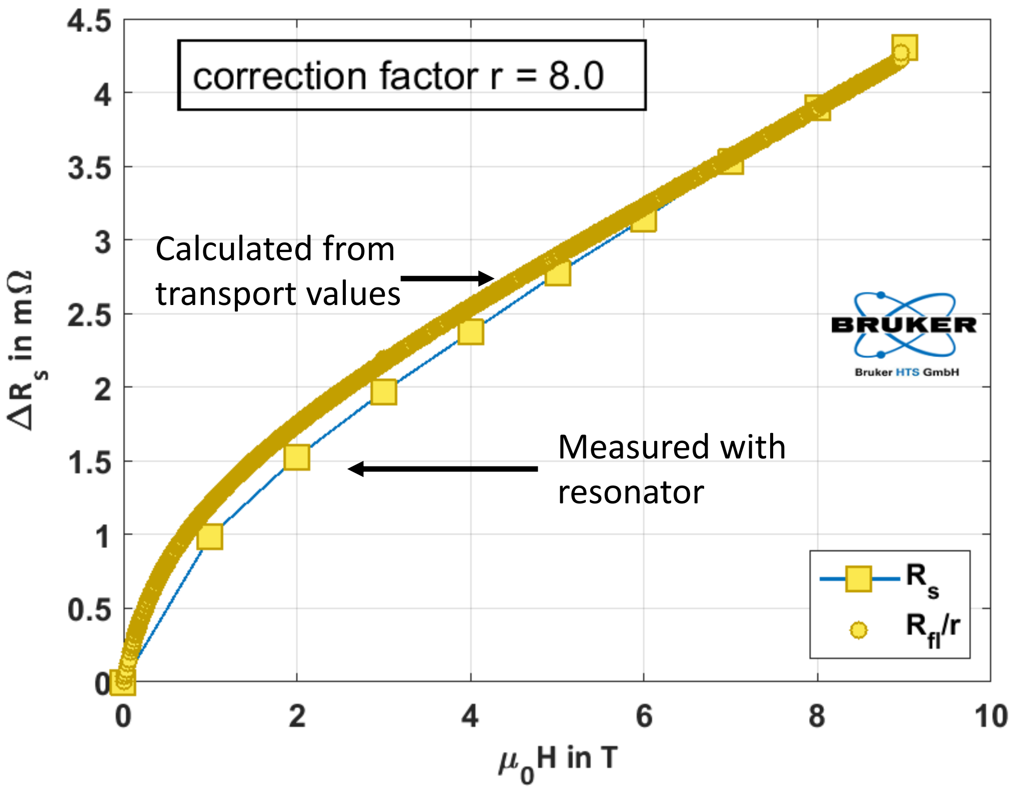
Overestimation of R_s with rigid-fluxon model:

$$R_{fl}(T,H,\nu) = R_n \sqrt{\sqrt{a^2(J_c,\rho,B_{c2}) + b^2(J_c,\rho,B_{c2})} - b(J_c,\rho,B_{c2})}$$

Introducion of correction factor r:

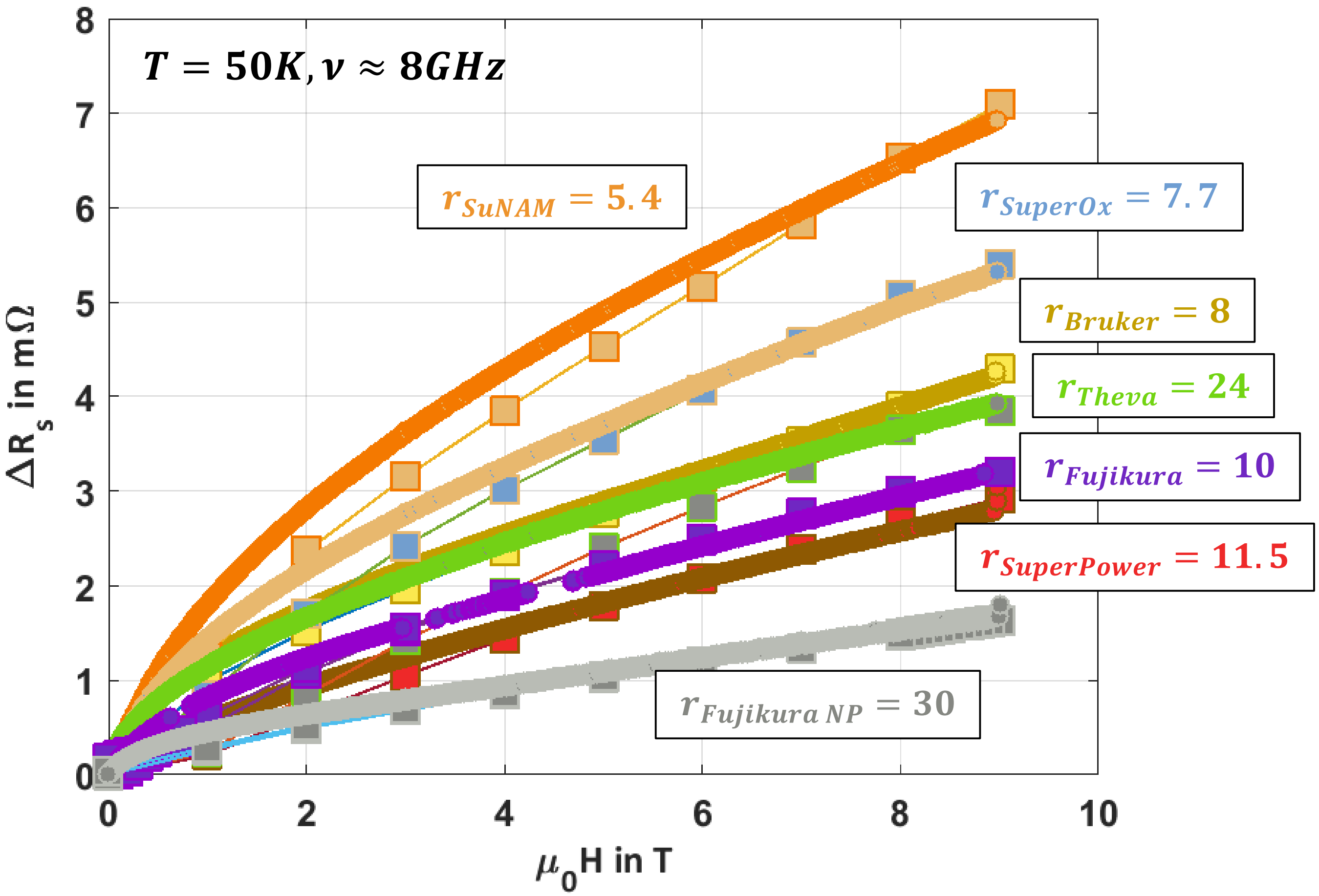
$$R_{fl}(T,H,\nu)/r$$

$T = 50K, \nu \approx 8GHz$

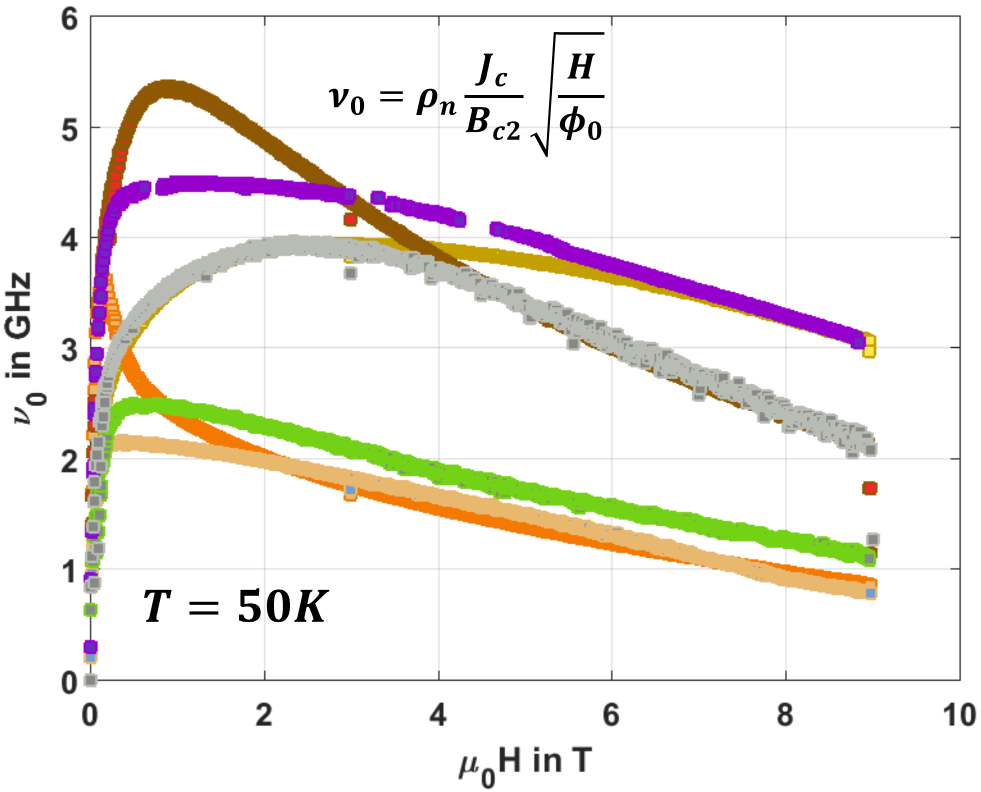


2. Linking R_s to microstructure

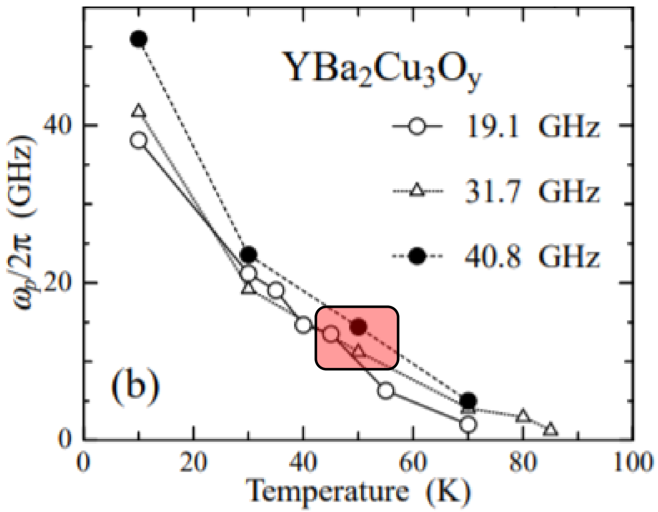
Correction factor r depends on the microstructure of CC



2. Linking R_s to microstructure



Tsuchiya, Yoshishige, et al. "Electronic state of vortices in YBa2CuO7-x investigated by complex surface impedance measurements." *Physical Review B* 63.18 (2001): 184517.



Underestimation of ν_0 compared to literature $\nu_0^{lit}(50K) \geq 15GHz$.

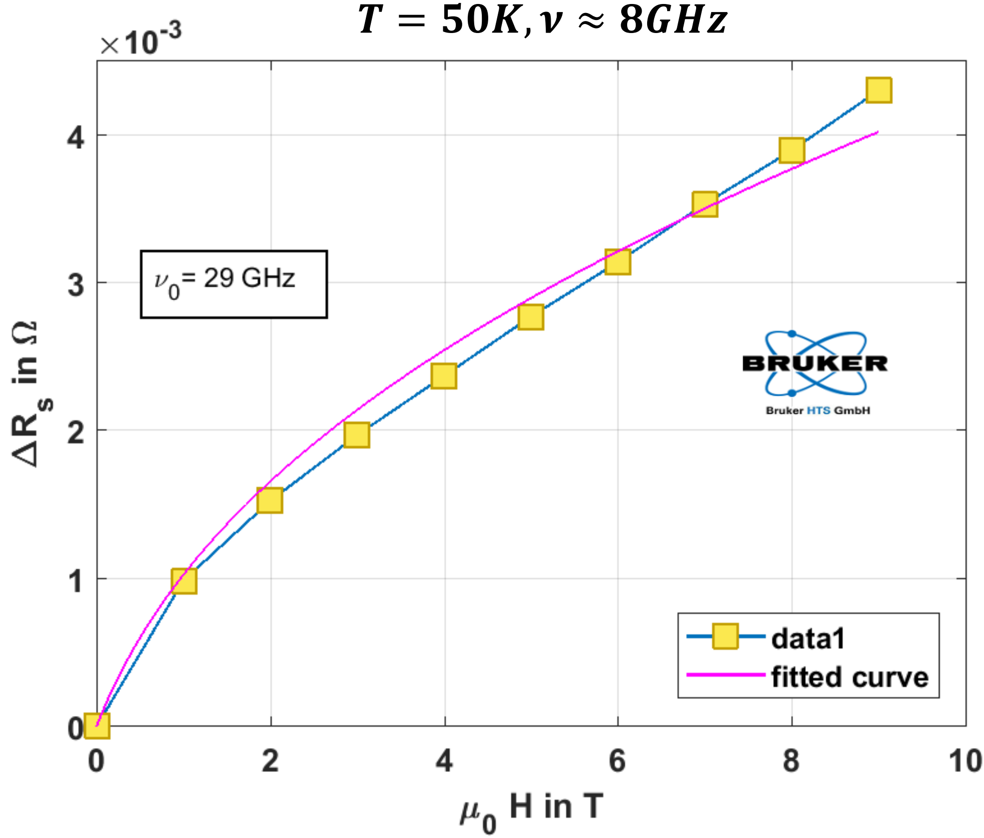
2. Linking R_s to microstructure

Ignore the depinning frequency derived from rigid-fluxon model:

$$\nu_0 = \rho_n \frac{J_c}{B_{c2}} \sqrt{\frac{H}{\phi_0}}$$

→Use ν_0 as fitting parameter.

$T = 50K, \nu \approx 8GHz$

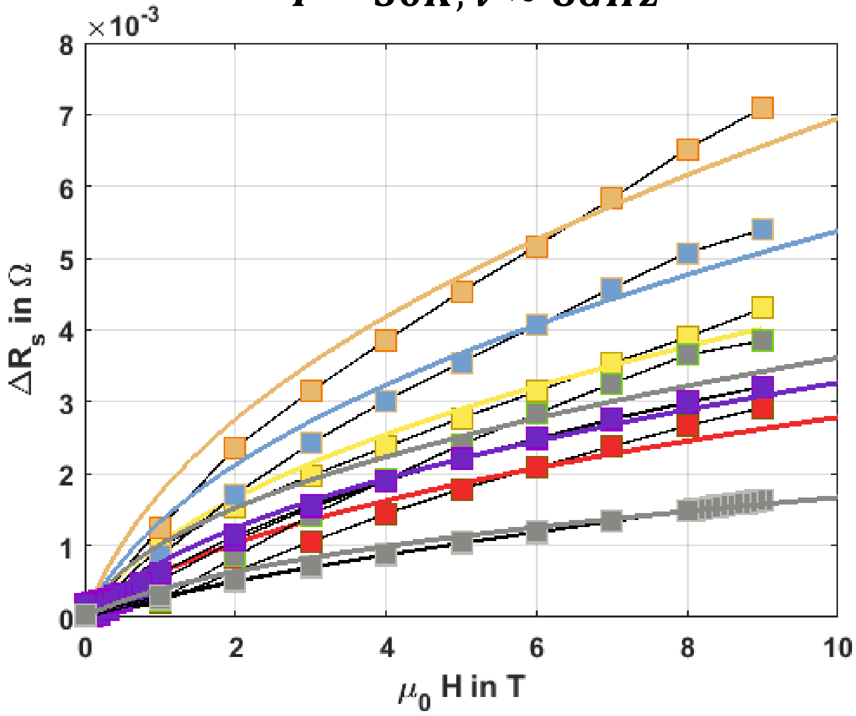


Fitted value $\nu_0 \approx 29\ GHz$:

1. No correction factor needed
2. Matches better with literature

2. Linking R_s to microstructure

$T = 50K, \nu \approx 8GHz$

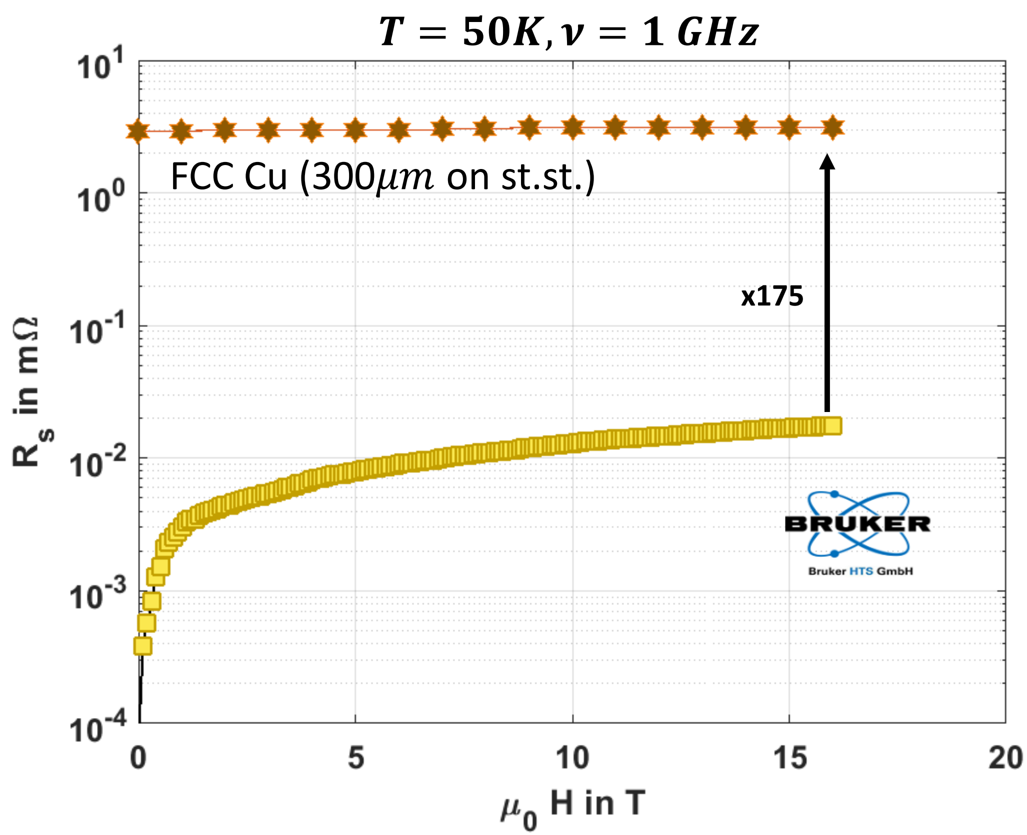


Provider	$\nu_0^{rigid-fluxon}$ (9T) in GHz	$\nu_0^{fit\ rigid-fluxon}$ in GHz	$\nu_0^{CoffeyClem}$ in GHz
Bruker	3.0	29.3	30.0
SuNAM	0.9	19.6	19.0
SuperOx	0.8	25.1	24.5
SuperPower	1.2	35.4	35.2
Theva	3.1	60.4	57.0
Fujikura	3.3	33.9	34.2
Fujikura NP	1.3	67.8	71.0

$\nu_0^{rigid-fluxon} = \rho_n \frac{J_c}{B_{c2}} \sqrt{\frac{H}{\phi_0}}$ **identified as weakness of model→ Gives potential to adjust model.**

2. Linking R_s to microstructure

Extrapolation of R_s using rigid-fluxon model with $\nu_0^{fit\ rigid-fluxon}$ to 1GHz and 16T:



Predicted by rigid-fluxon model: Out performance of Cu by HTS CC at FCC conditions even more pronounced!

Outline

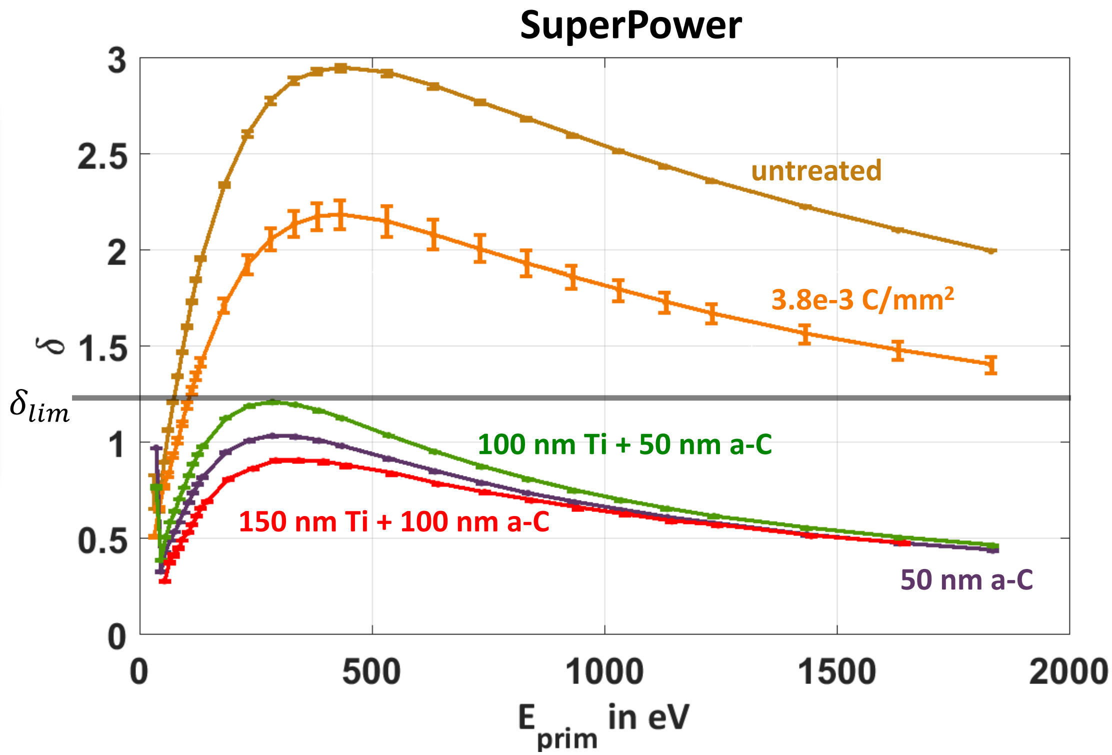
1. *REBCO CCs for beam screen coating*

2. *Linking CC´s surface resistance to microstructure*

3. ***Evaluation of secondary electron yield***

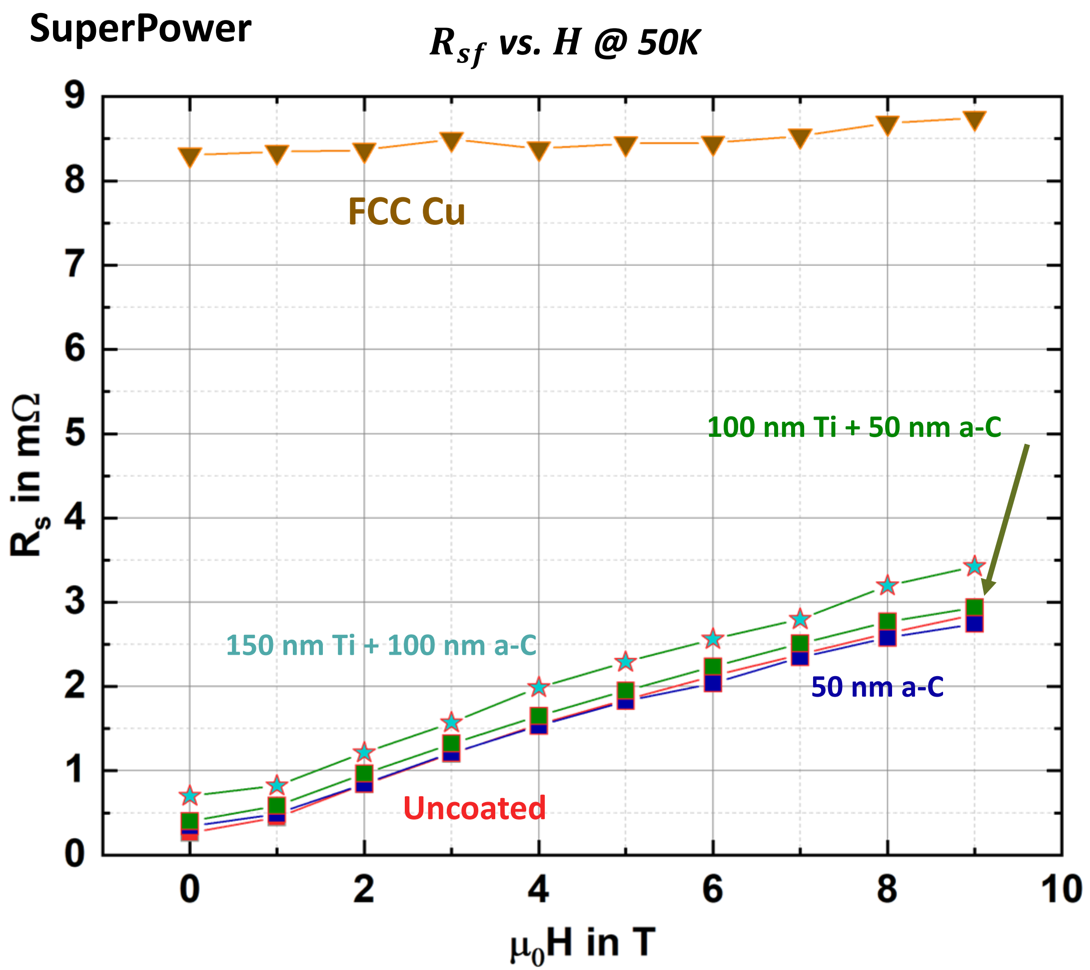
3. Beam instability: Secondary electron yield

- In untreated form not suitable for use in particle accelerators
- Conditioning treatment not sufficient
- Roughness of a-C decreases SEY under desired limit
- Ti as adhesion and protection layer



Thin layers of a-C and Ti decrease the SEY below threshold value 1.3.

3. Beam instability: Secondary electron yield



Increase of R_s for 150 nm Ti + 100 nm a-C not detrimental.

Conclusions

- State of the art REBCO CCs outperform Cu at 50K, 8 GHz and up to 9T
- Extraction of ν_0 as for all CCs by means of ridig-fluxon model
- Extrapolation of surface resistance to FCC conditions 1 GHz, 16 T, 50K → outperformance of Cu by CCs by two order of magnitude expected at FCC conditions
- a-C (50-100 nm) and Ti (100-150 nm) capping to reduce the secondary electron yield below required limit $\delta_{\mathrm{lim}} \approx 1.3$
- Increase in R_s due to capping is not significant at 50K, 8GHz, up to 9T

Outlook: $REBa_2Cu_3O_7$ coated conductors for beam screen coating

1. Characterization of CCs up to 16T:

New cryostat with 16 T SC magnet to be installed in Q1 2020 at ICMAB.

Compatible with

- Cylindrical dielectric resonator $\nu \approx 8$ GHz
- Resonator configuration with $\nu \approx 1$GHz (currently in development at UPC/ALBA)

Surface impedance Z_s measurable at FCC conditions.

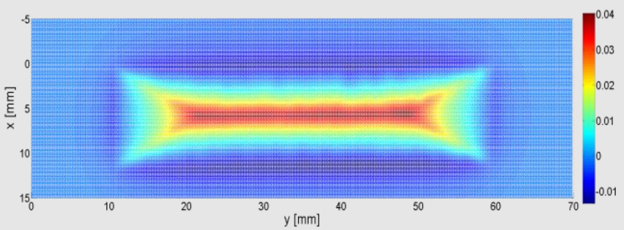
- $\nu = 1\ GHz, 8GHz$
- Wide Temp. range
- Up to 16 T

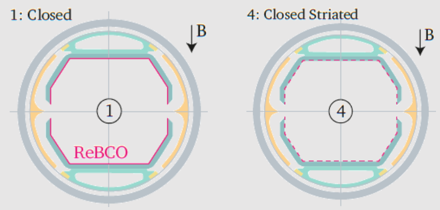
→ **Understanding the influence of magnetic field on vortex dynamics up to 16T.**

2. Evaluation of persistent currents

- Analyzing persistent currents will define the required aspect ratio of Cu and REBCO CC in beam screen

Hall mapping measurement of CC done at ICMAB

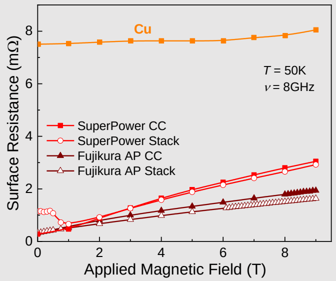




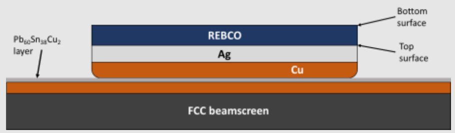
- Construction of proof-of-concept device based on generated knowledge

3. Welding solutions of aC/REBCO/Steel stacks

Poster 448. Coating the FCC-hh beam screen chamber with REBa2Cu3O7-x coated conductors at FCC week 2019



- Soldering of REBCO CCs to st. st. with delamination of superconducting layer possible in large scales
- Delaminated bottom layer shows no degradation in R_S performance



- Superconducting perfomance of delaminated layers still to be investigated

4. Mechanical tests of aC/REBCO/Steel stacks

- Experimental system to assess 2D /3D stress maps based in optical image correlation with in situ monitoring the I_c has been finished and will be taken into operation in Q3/Q4 2019
- Full evaluation of stresses accociated to new welding solution targeted

Acknowledgement

The authors acknowledge the support and samples provided by Bruker, Fujikura, Sunam, SuperOx, SuperPower and Theva. Authors acknowledge CERN funding FCC-GOV-CC0073/1724666/KE3359, MAT2014-51778-C2 COACHSUPENERGY, 2017-SGR 1519 from Generalitat de Catalunya and COST Action NANOCOHYBRI (CA16218). ICMAB authors acknowledge the Center of Excellence award Severo Ochoa SEV2015-0496 and its Future Interdisciplinary Projects action.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 754397".

Financial support from the Spanish Ministry of Science, Innovation and Universities, through the "Severo Ochoa" Programme for Centres of Excellence in R&D (SEV-2015-0496)

Thank you for your attention!