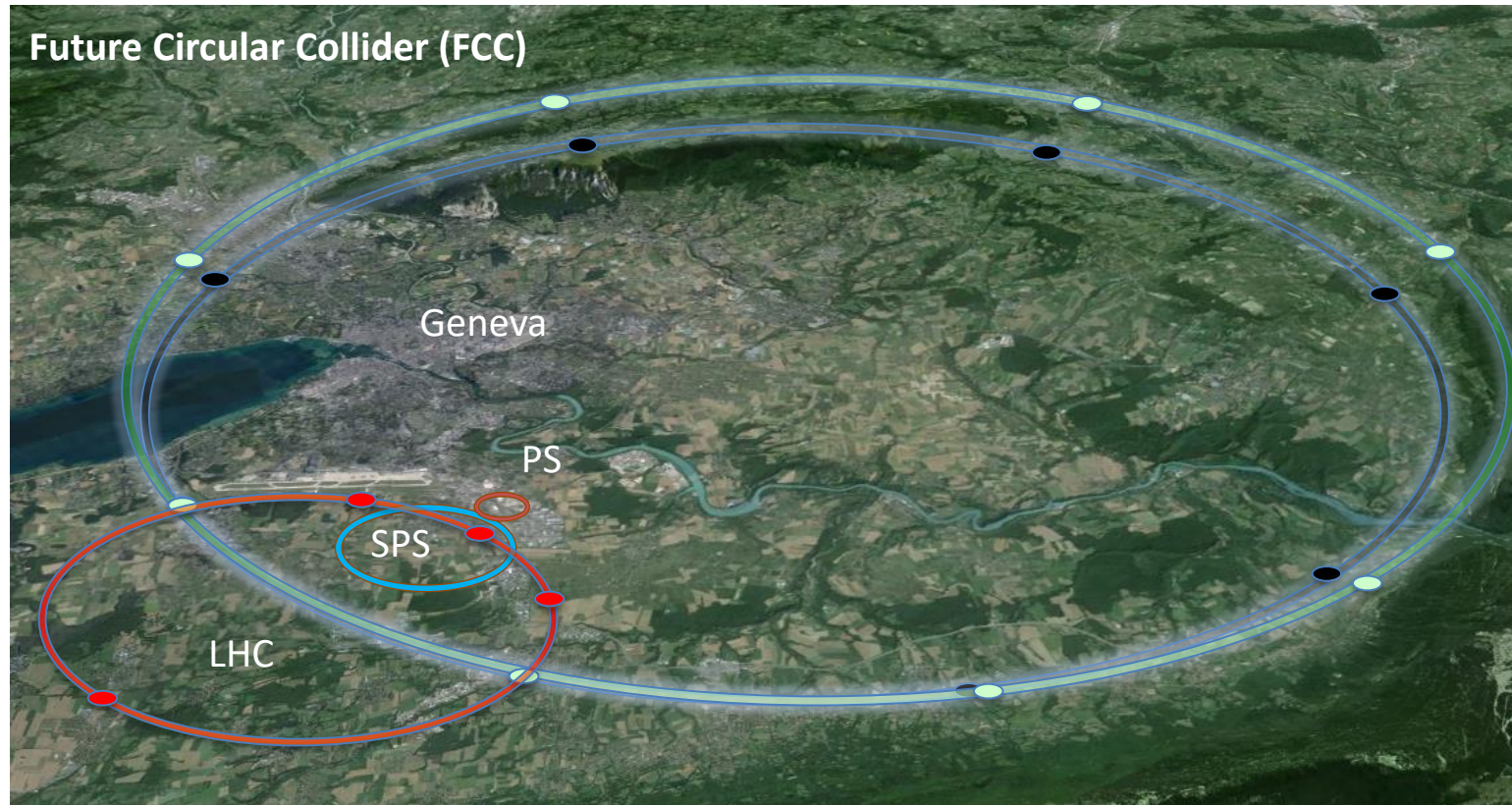


# HTS Coated Conductors for beam impedance reduction in the FCC-hh



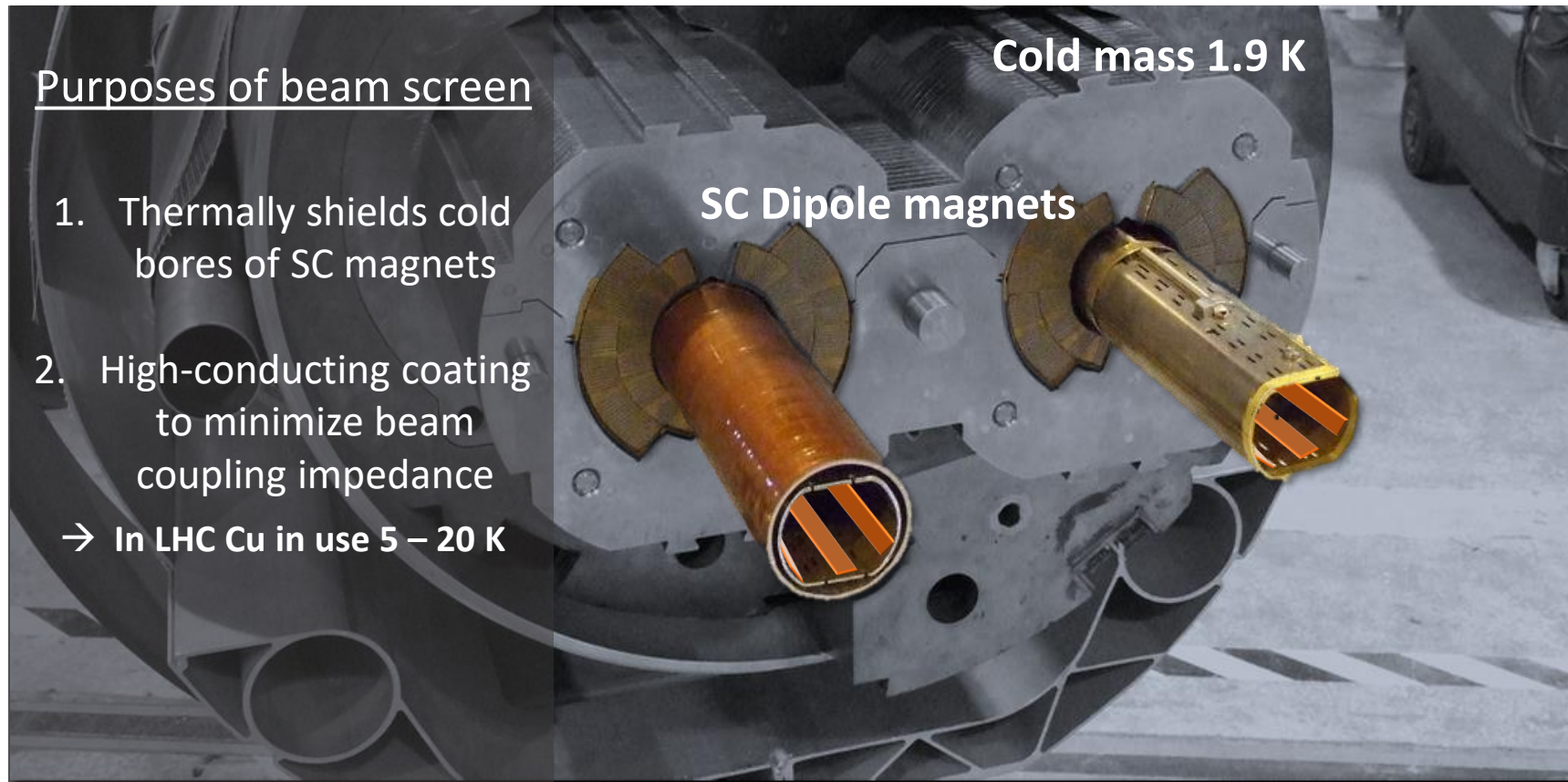
Joffre Gutierrez Royo\*

A. Romanov, G. Telles, N. Lamas, P. Krkotic, J. O'Callaghan, X. Granados, E. Garcia-Tabarés, M. Taborelli, P. Chiggiato, I. Korolkov, R. Miquel, F. Perez, M. Pont, T. Puig, S. Calatroni

# Synchrotron Radiation and Image currents: the FCC R&D challenge for the beam screen chamber

*In a circular collider **charged particles** lose energy by emitting **synchrotron radiation**.*

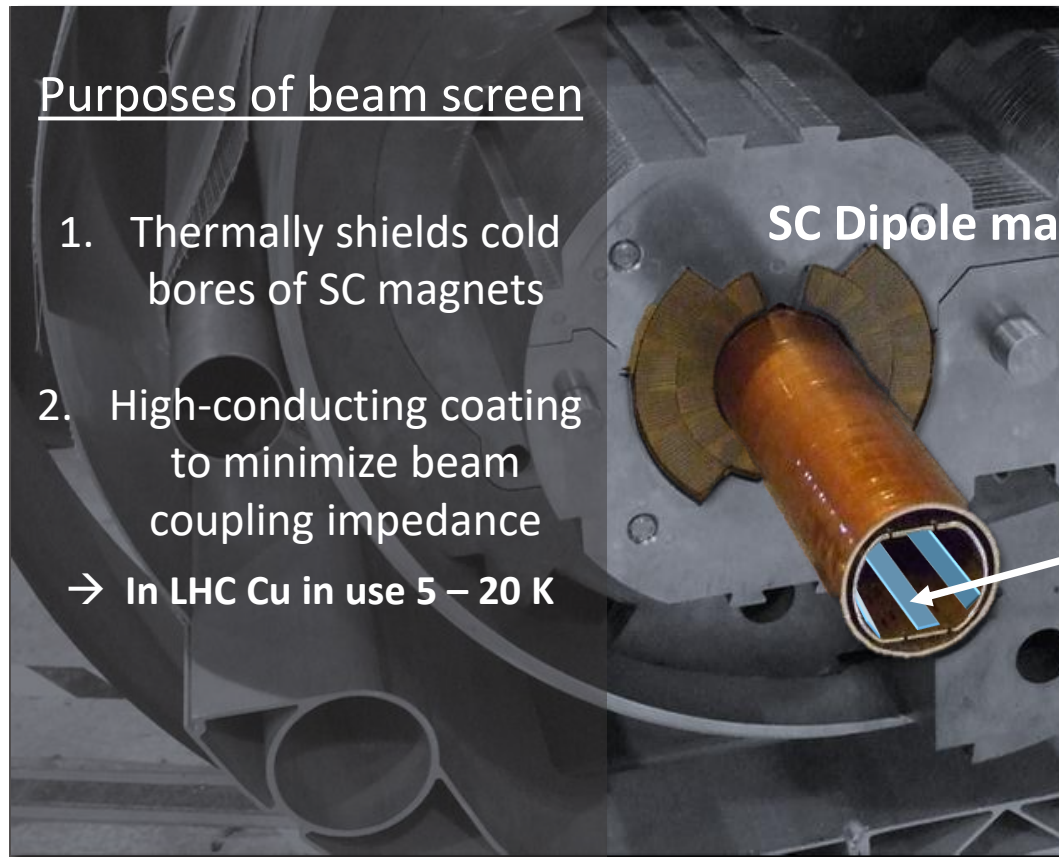
Cross section LHC dipole



# Synchrotron Radiation and Image currents: the FCC R&D challenge for the beam screen chamber

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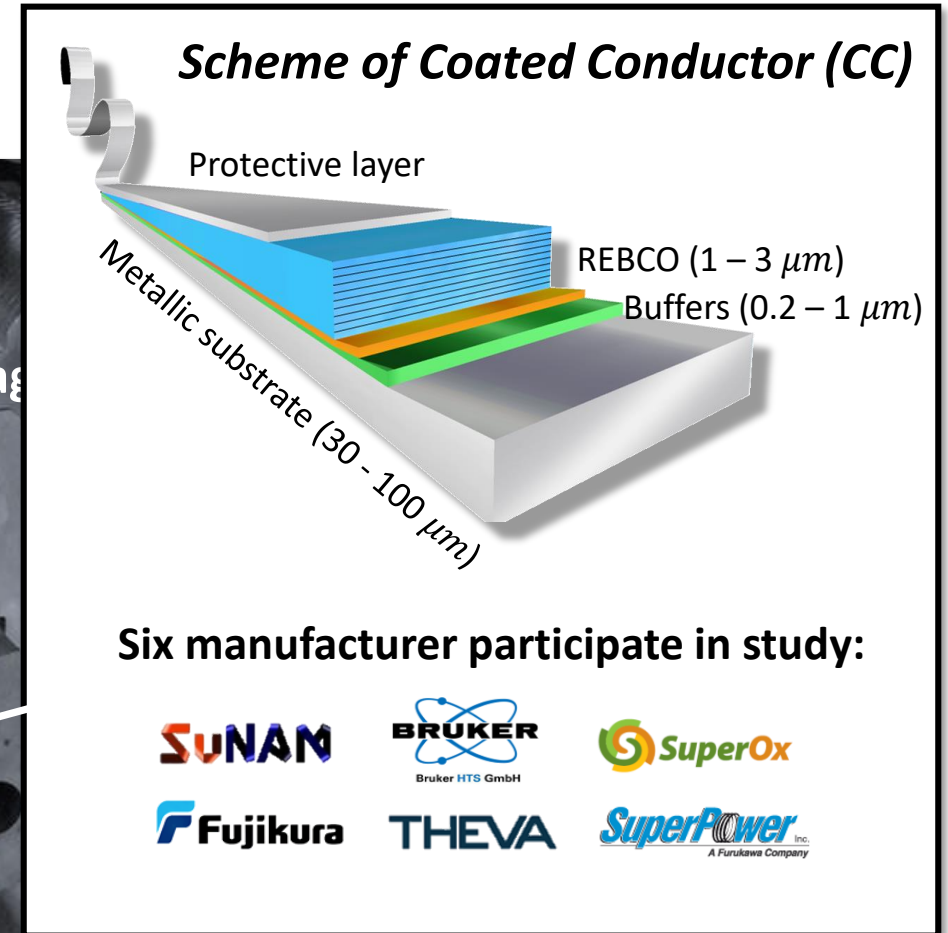
Cross section LHC dipole



## Purposes of beam screen

1. Thermally shields cold bores of SC magnets
  2. High-conducting coating to minimize beam coupling impedance
- In LHC Cu in use 5 – 20 K

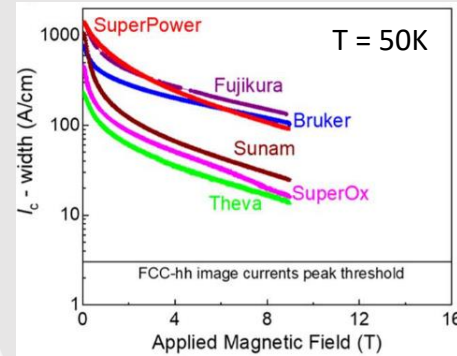
SC Dipole mag



# CCs present a solution for the FCC's beam-screen chamber

FCC working conditions: 16 T, 50K, 1 GHz & 25 A peak

## Withstanding induced image currents

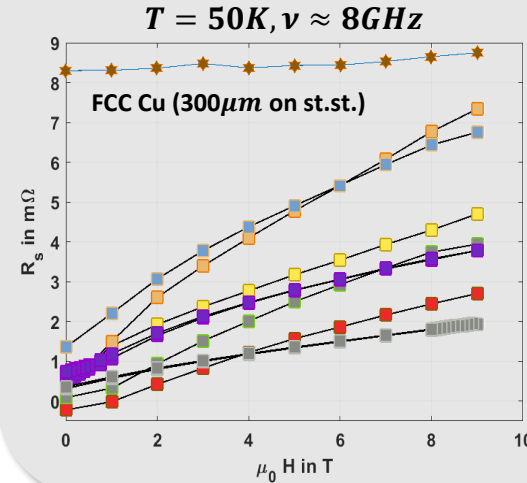


|            | Rare-earth | Nano-inclusions    | REBCO thickness ( $\mu\text{m}$ ) | Growth method |
|------------|------------|--------------------|-----------------------------------|---------------|
| Bruker     | Y          | BaZrO <sub>3</sub> | 1.6                               | DD-PLD        |
| Fujikura   | Gd         | None               | 1.8                               | PLD           |
| Sunam      | Gd         | None               | 1.6                               | RCE-DR        |
| SuperOx    | Gd         | None               | 0.9                               | PLD           |
| SuperPower | Y,Gd       | BaZrO <sub>3</sub> | 1.5                               | MOCVD         |
| Theva      | Gd         | None               | 3                                 | EB-PVD        |

Characterization of tape architecture

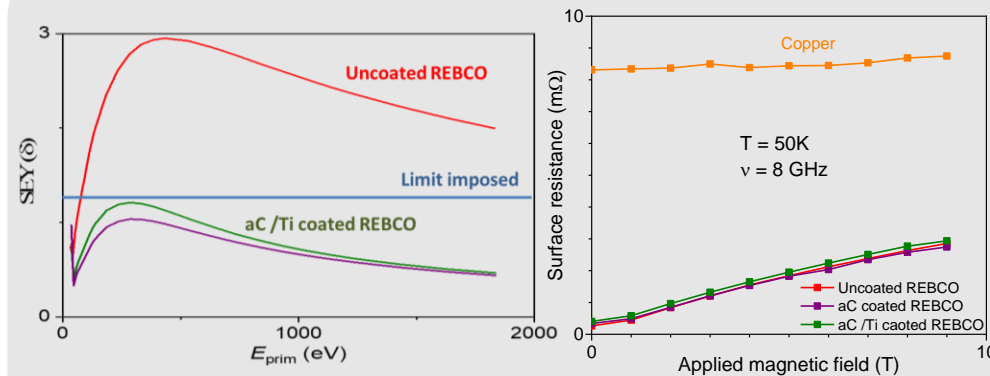
CCs prospected to sustain induced 25 A peak currents

## Surpassing Cu in terms of RF conductivity



CCs outperform  $T = 50\text{ K}$ ,  $\nu = 8\text{ GHz}$  and up to  $B \approx 9\text{ T}$

## Preventing electron-cloud generation



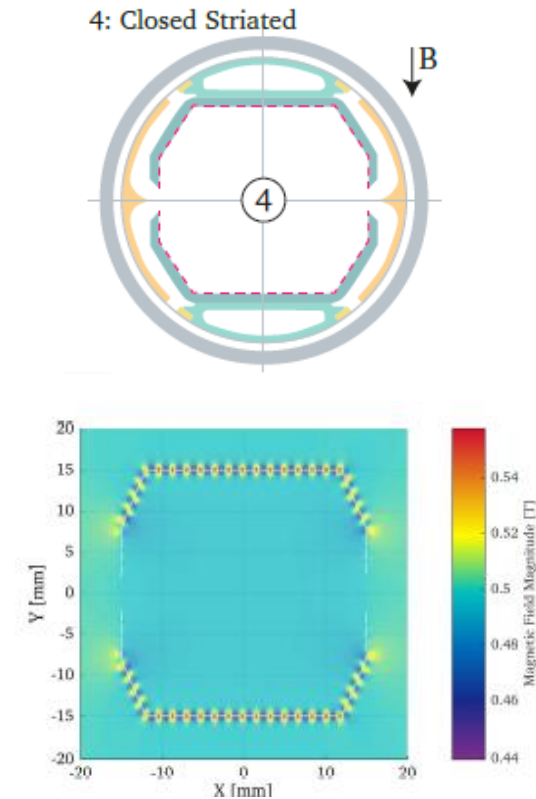
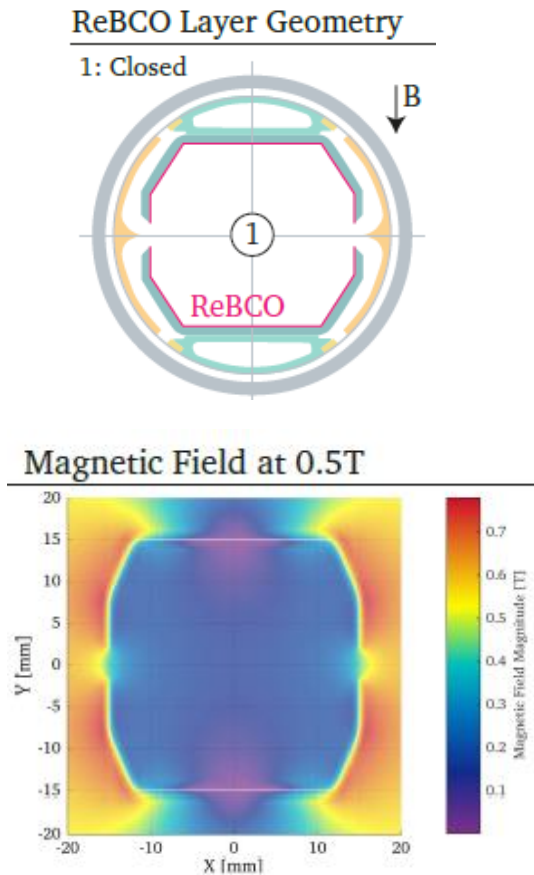
- Identified thin a-C layer to decrease SEY below 1.3
- Increase in  $R_s$  for coated SC not detrimental

What about the **trapped magnetic field** inside the SC?

**Magnetic field homogeneity** inside beam-screen chamber better than  $10^{-4}$

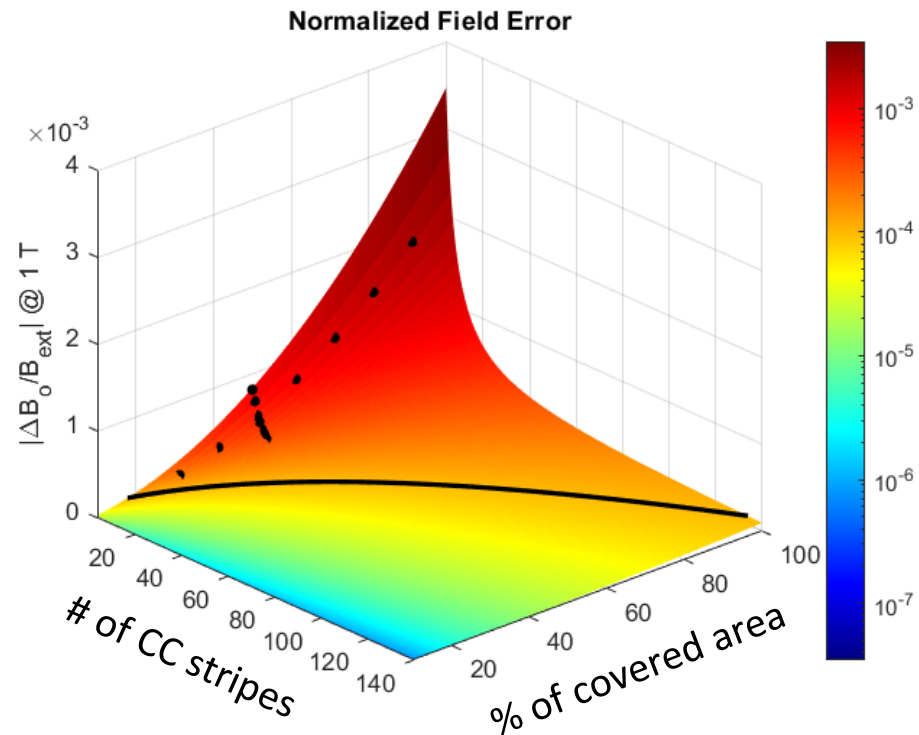
# Striated configuration to minimize trapped fields

**Screening currents** during magnetic field ramping will produce unacceptable **field quality** effects



**A striated geometry** will drastically reduce trapped magnetic fields in the superconductor, recovering **acceptable levels of field quality**

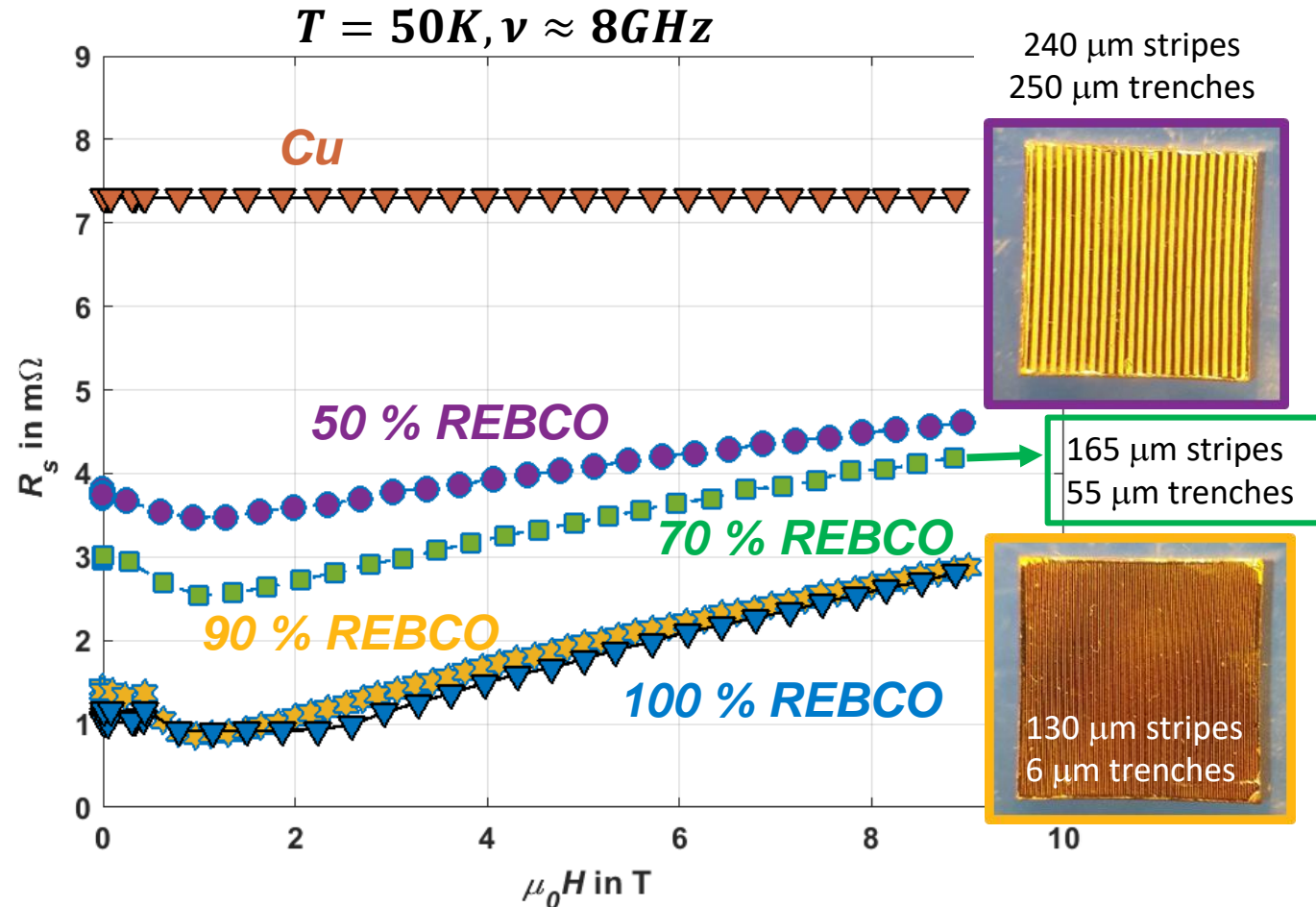
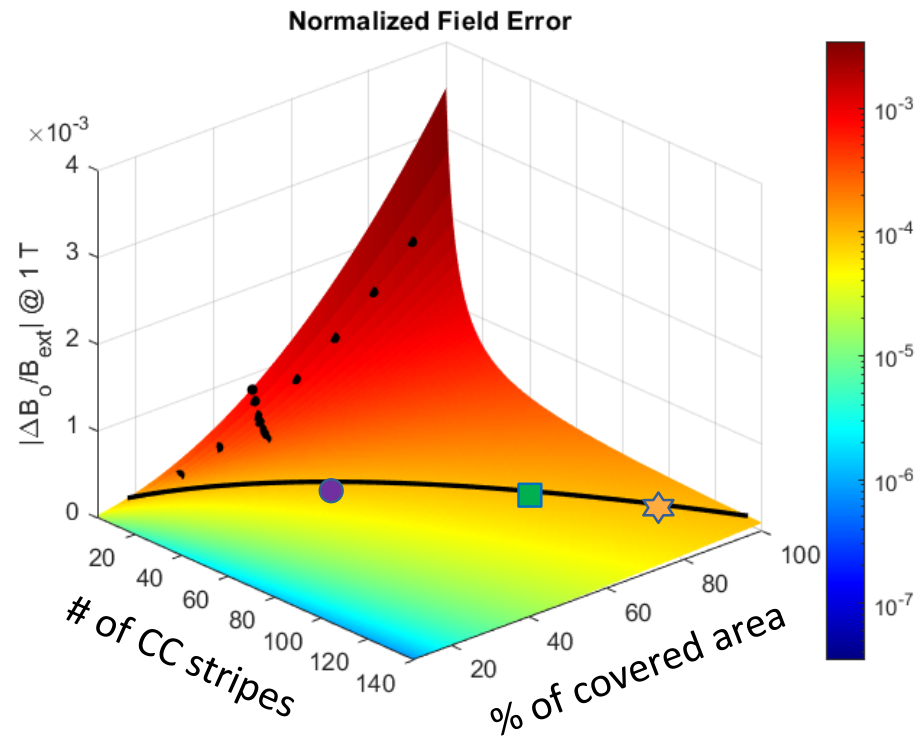
# A wide area of parameters guarantees 1 part over $10^4$ in magnetic field homogeneity and better than Cu R<sub>s</sub>



Our simulations incorporate:

- real  $J_c(H, T)$  data
- flux creep
- REBCO anisotropy
- ac-shacking due protons-induced  $H_{rf}(\nu)$

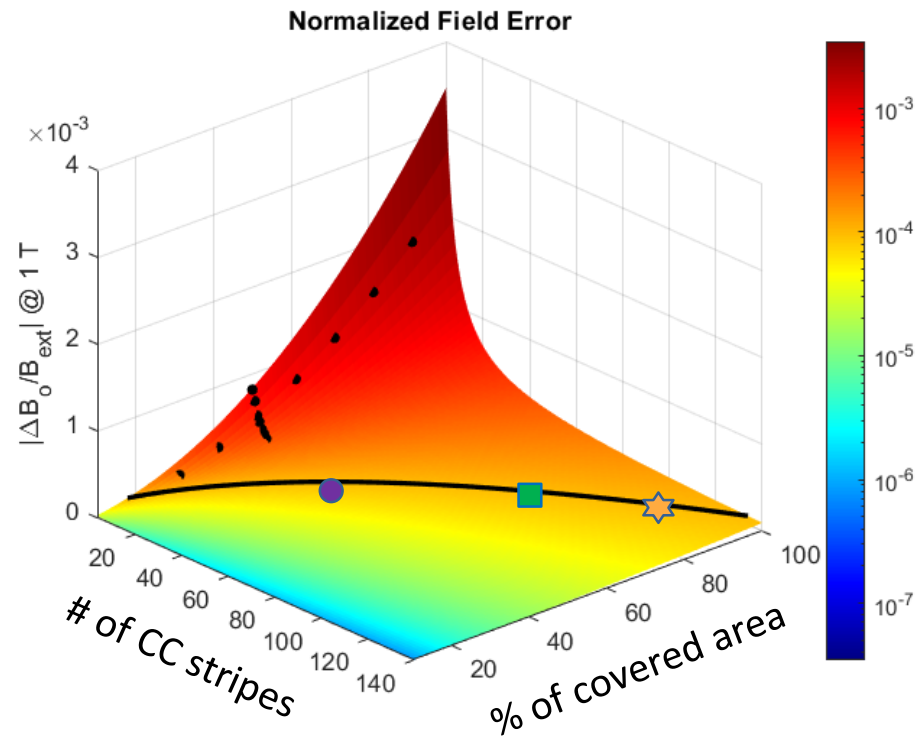
# A wide area of parameters guarantees 1 part over $10^4$ in magnetic field homogeneity and better than Cu $R_s$



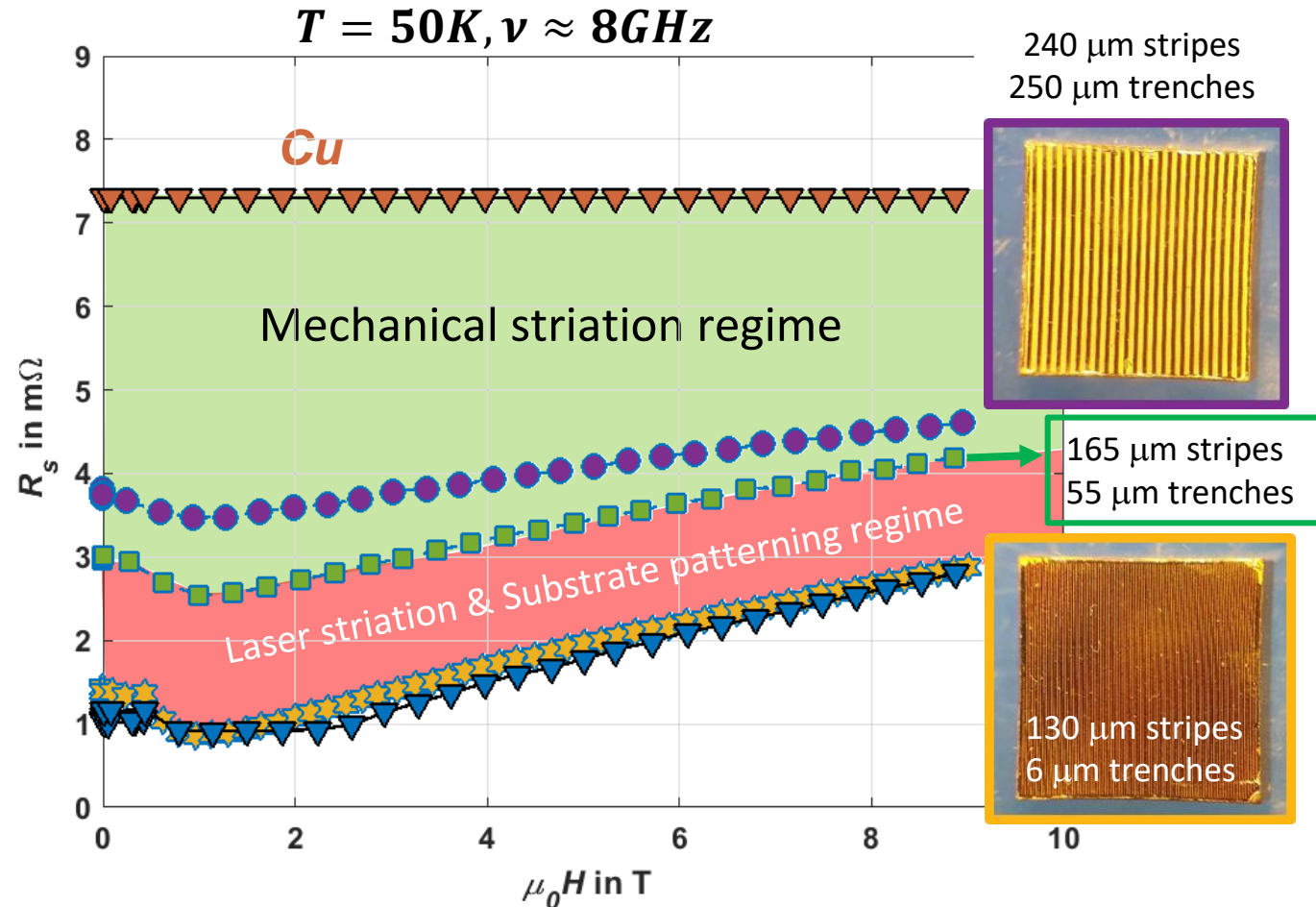
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First experimental data shows promising results

# A wide area of parameters guarantees 1 part over 10<sup>4</sup> in magnetic field homogeneity and better than Cu R<sub>s</sub>



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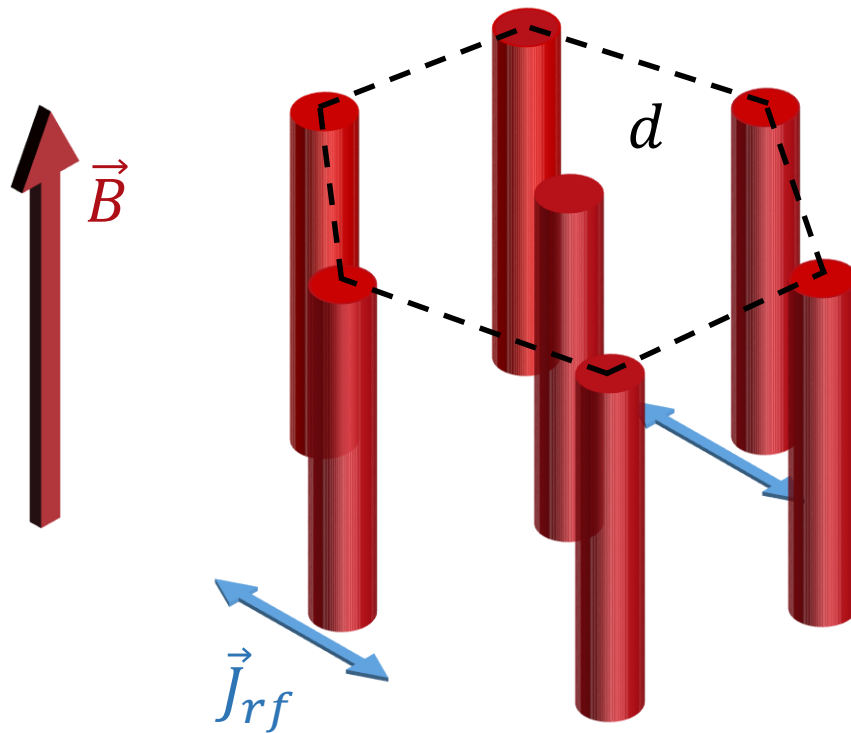


First experimental data shows promising results  
**Technology is scalable**

# The Gittleman-Rosenblum model describes the microwave response of the mixed state

The Gittleman-Rosenblum model in a nutshell

Flux tube lattice



- Not considering thermal contributions
- Assuming  $\vec{F}_{v-v} \gg \vec{F}_{pinning}$

Equation of motion for fluxons:

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

The vortex resistivity is :

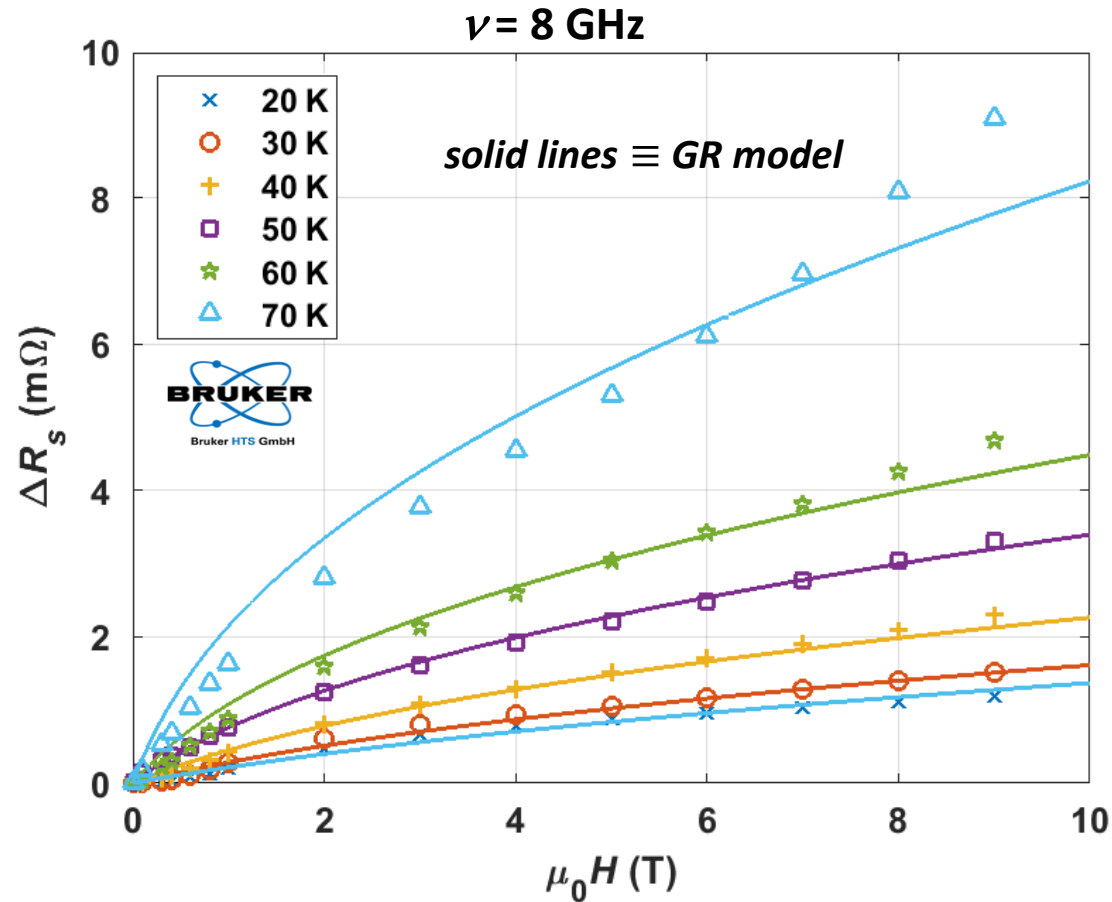
$$\rho_v = \frac{B\Phi_0}{\eta} \frac{1}{1 - i \frac{\omega_p}{\omega}} \quad \text{Fitting parameter}$$

$$\text{With } \eta = 1.45 \frac{\phi_0 B c^2}{\rho_n}$$

$$Z_s = i\omega\mu_0 \sqrt{\lambda_l^2 - i \frac{\rho_v}{\mu_0\omega}}$$

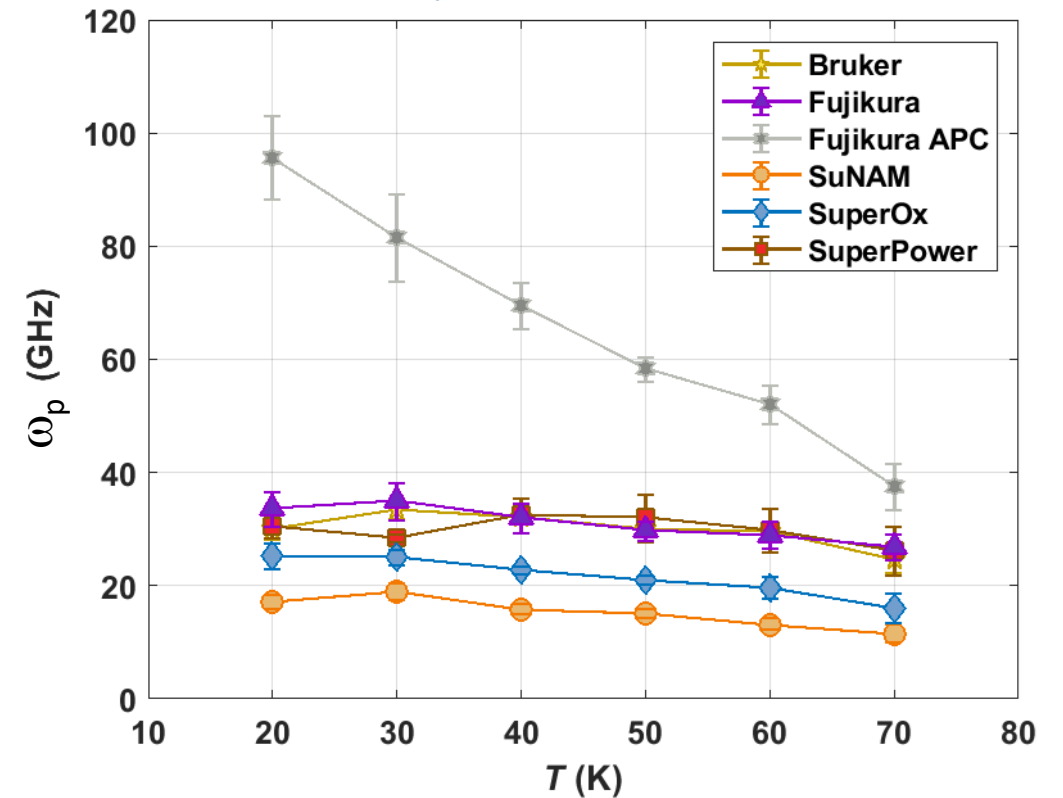
# Gittleman-Rosenblum shows excellent agreement with experiments

Fitting of field dependent part of  $R_s$  with G-R model



A. Romanov, et al. Scientific reports 10 (2020)

Estimation of  $\omega_p$  by means of fitting G-R model

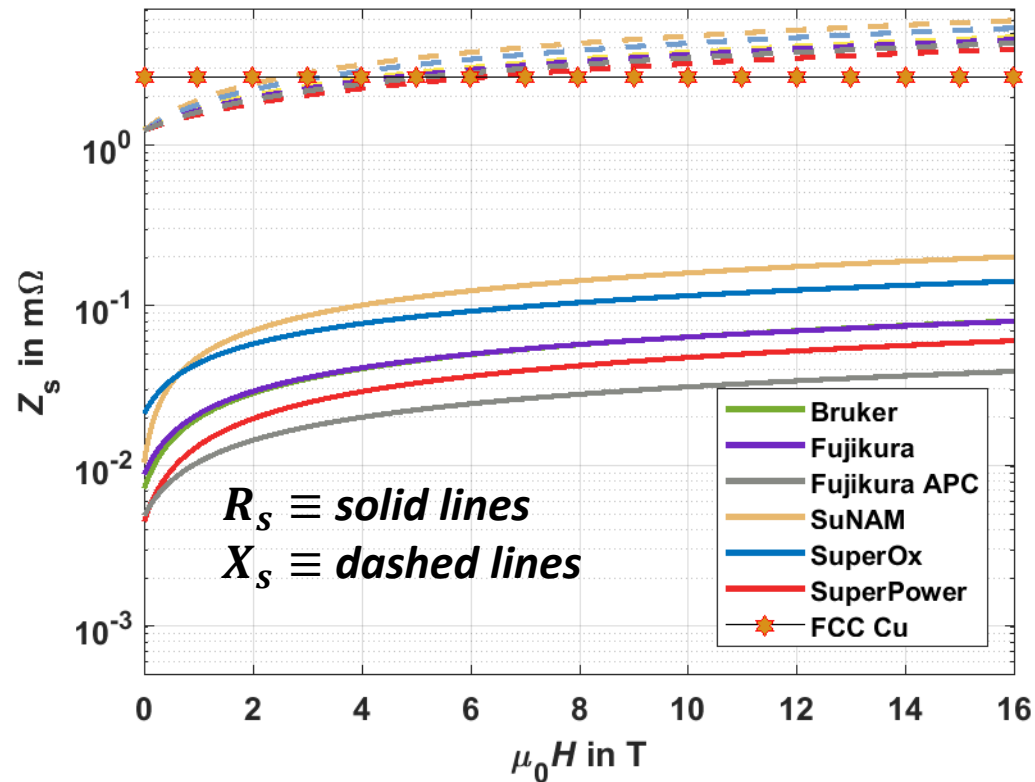


We can reconstruct  $Z_s$  and make predictions

# G-R model predicts a further gain under FCC conditions

Extrapolation of surface impedance  $Z_s = R_s + iX_s$  within Gittleman-Rosenblum model to FCC conditions.

$T = 50 \text{ K}, \nu = 1 \text{ GHz}$



A. Romanov, et al. Scientific reports **10** (2020)

At FCC conditions

CCs expected to outperform Cu in terms of  $R_s$  by a factor of  $\approx 15 - 70$ .

Surface reactance:  $X_s^{CC} \approx X_s^{Cu}$

## Future Perspectives

Generate experimental data of  $V-I(T, B)$  and  $Z_s(T, B)$  up to 16T and down to 1 GHz

New equipment at ICMAB:

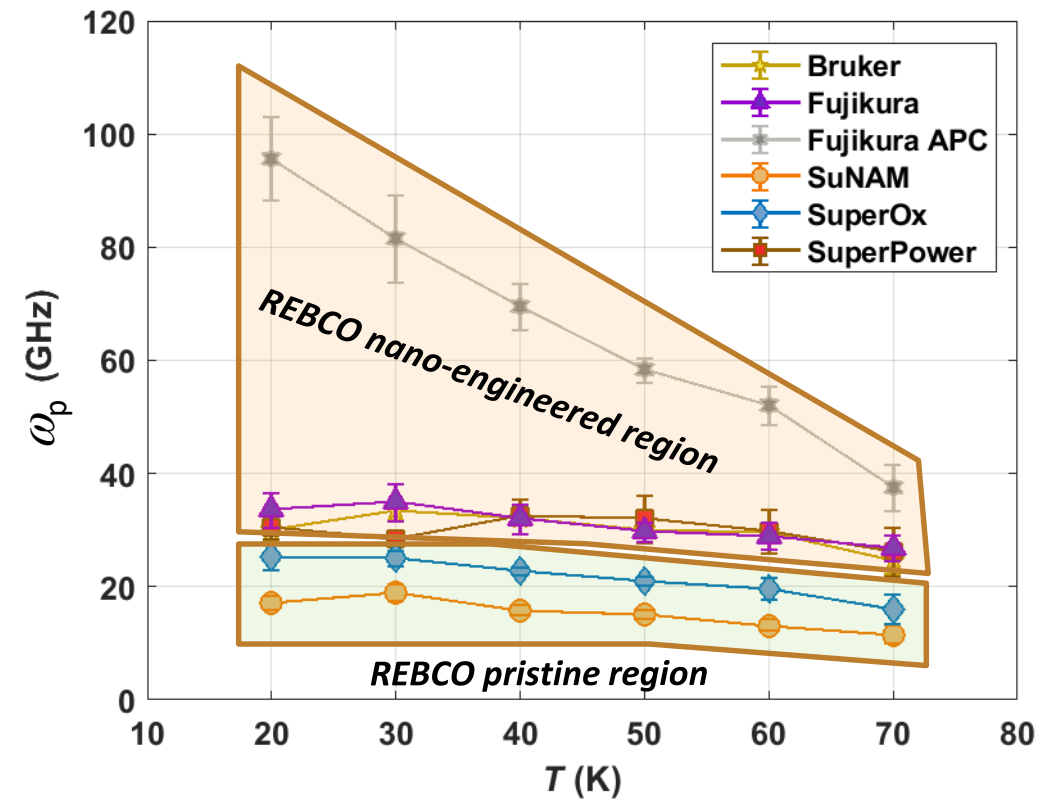
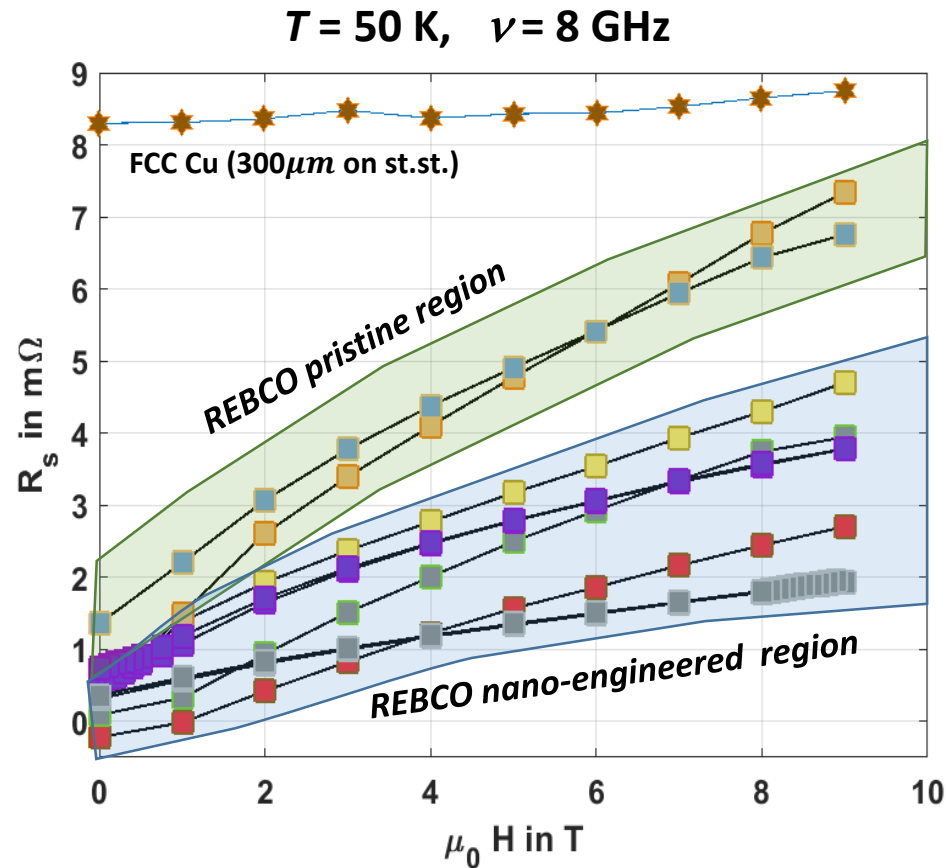
Multipurpose cryostat with VTI 1.5 K – 325 K

50 mm bore 16 T magnet.

Parallel plate resonator down to 1 GHz

# Clear correlation between microstructure and microwave properties

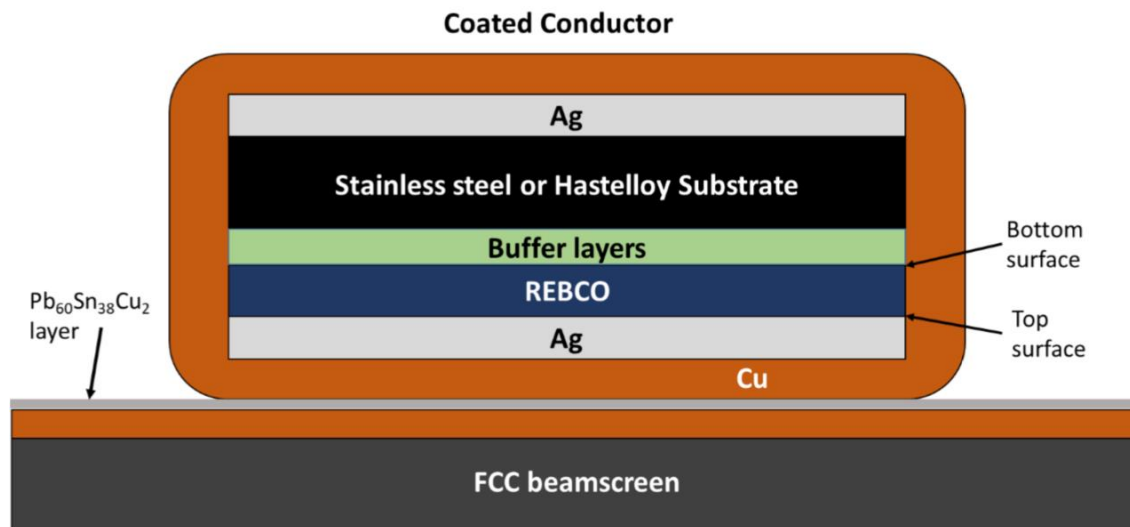
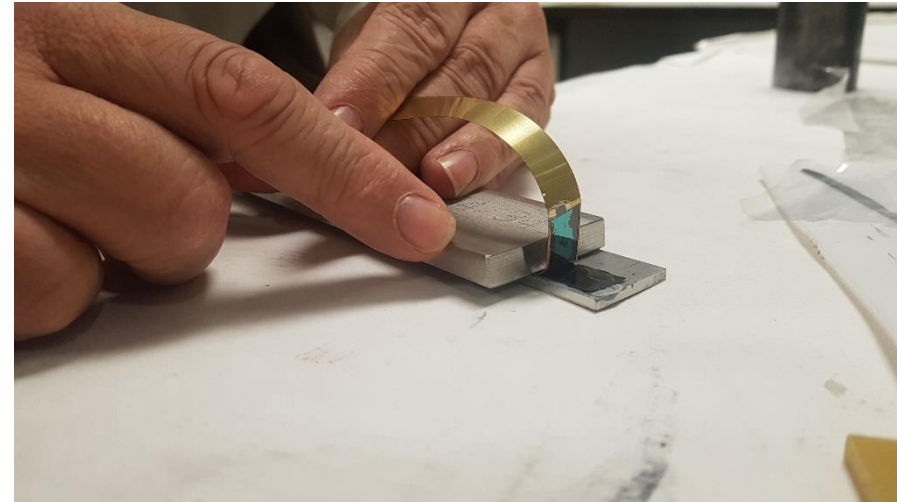
Estimation of  $\omega_p$  by means of fitting G-R model



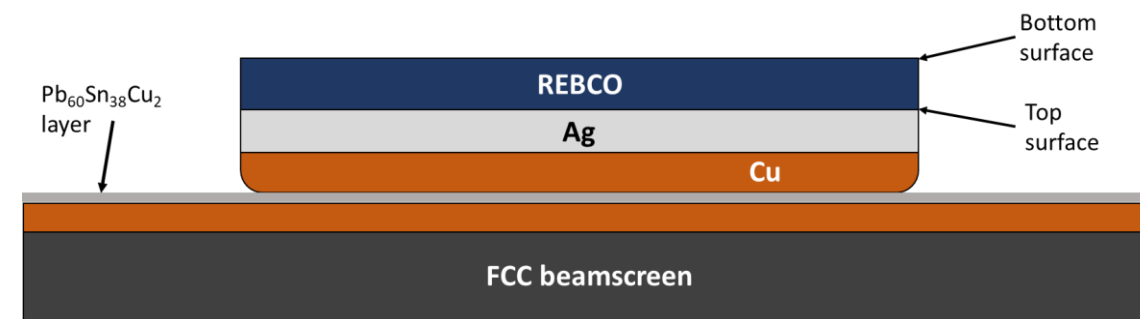
A. Romanov, et al. Scientific reports 10 (2020)

# Two-step delamination technique for large surface coatings with CCs

## Welding of CC with protected SC layer



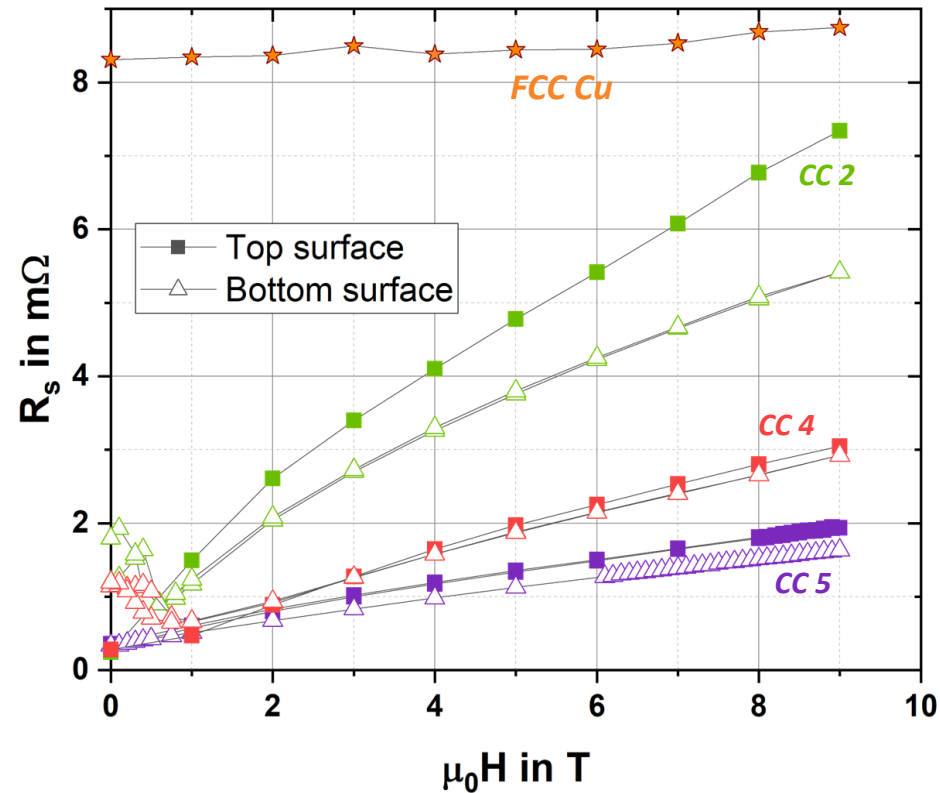
## Delamination in large scales possible



**Technology is easily scalable**

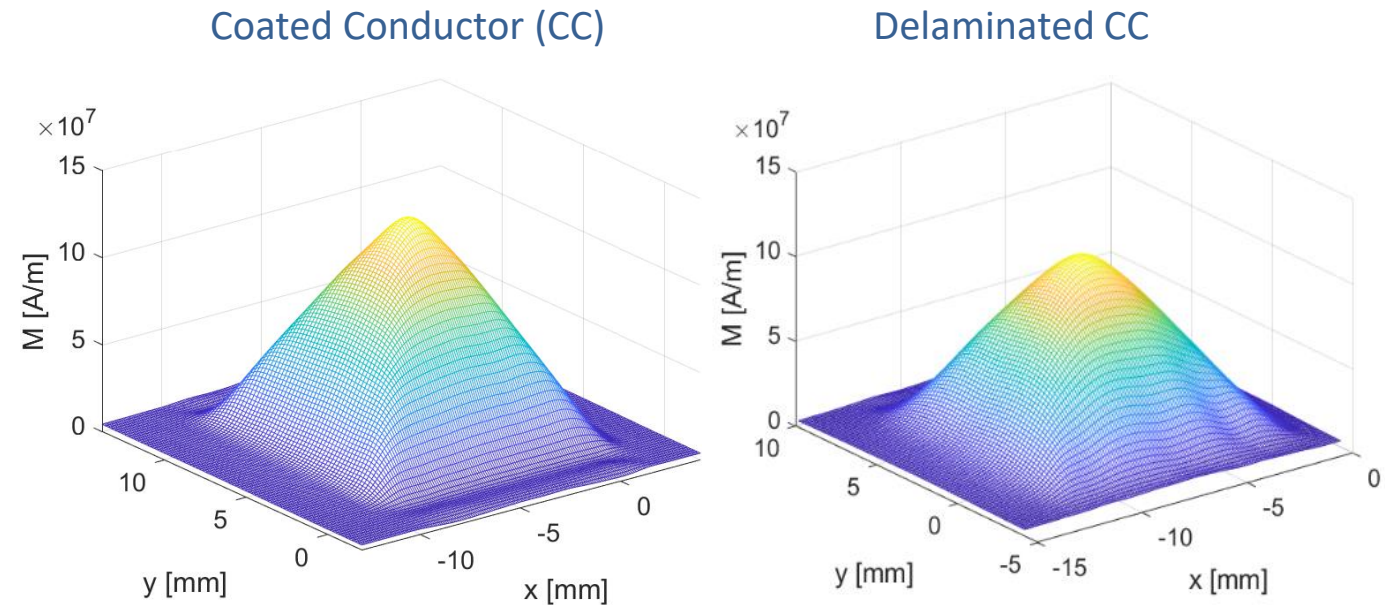
# Delamination does not damage material properties

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



Exposed surface improved  $R_s$

## Magnetization Hall-maps during the different steps at 77K

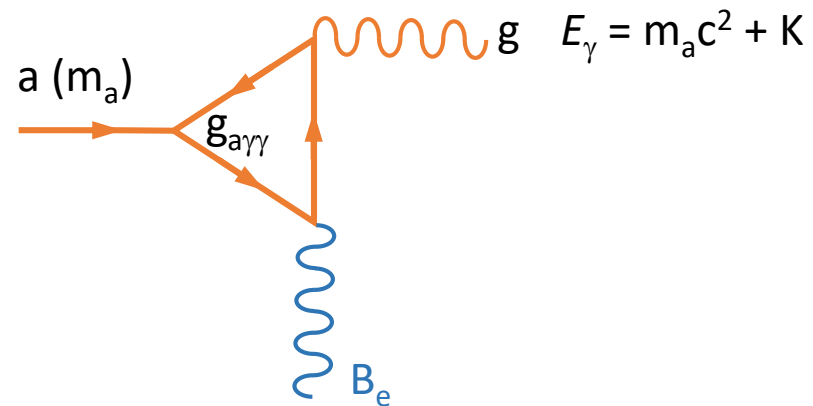


Good homogeneity

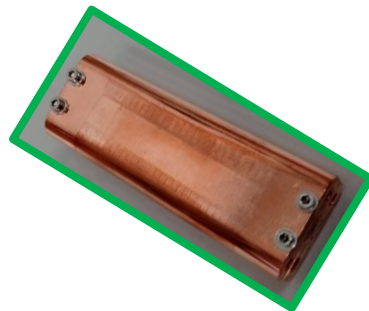
# Spin-off applications: Axion haloscope cavity

*In Collaboration with the RADES Project*

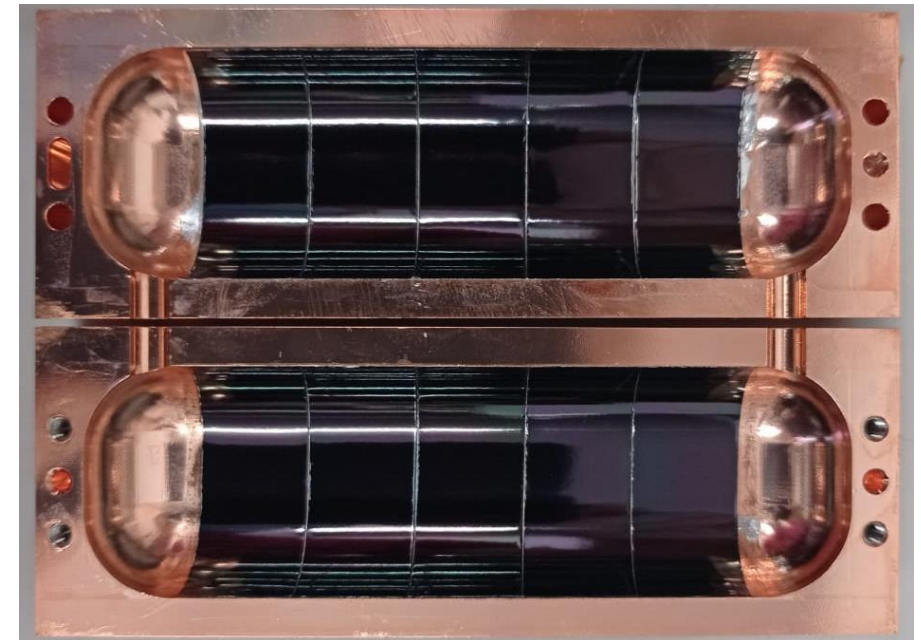
In the presence of a magnetic field  
DM Axions convert into monochromatic photons



DM Axion cavity of  $\nu = m_a c^2 / h$



$$P \propto B_e^2 Q V G$$



CC coated Axion cavity

$Q(0T, 4.2K) \sim 80k$

$Q(11T, 4.2K) \sim 60k$

Better than Cu!

Recent tests suggest a 5 times fold improvement in Q is possible! 15

# Conclusions

## General:

- Demonstrated a link between REBCO HTS  $\mu$ -structure and its microwave response.
- Commercial REBCO Coated Conductors available on km scale with high frequency properties of low dissipation  $\rightarrow$  Mature technology for RF applications.
- We present a scalable technology to coat surfaces with Coated Conductors

## FCC study:

- REBCO HTS exhibits lower  $R_s$  than Cu at  $T = 50$  K and 8GHz up to  $B = 9$  T.
- Modelling shows that  $R_s$  performance advantage of REBCO HTS becomes more pronounced at FCC-hh conditions.