High Temperature Superconductors for the FCC beam screen chamber

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EXCELENCIA SEVERO OCHOA
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CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

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Joffre Gutiérrez Royo

CommSensLab

EXCELENCIA MARÍA DE MAEZTU
2017 - 2020

IFAE
Institut de Física d'Altes Energies

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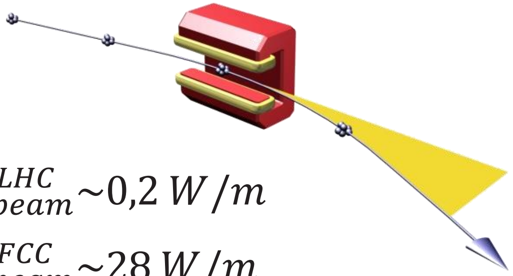
BIST
Barcelona Institute of Science and Technology

FCC week 2018
Amsterdam
9 – 13 April

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

Charged particles on a curved trajectory → Synchrotron Radiation

$$P_{beam} \propto \frac{B^2E^2N}{\rho}$$



$$P_{beam}^{LHC} \sim 0{,}2\ W/m$$

$$P_{beam}^{FCC} \sim 28\ W/m$$

Synchrotron Radiation will:

Heat up the 1.9 K cold bores

↓

Enormous increase cryogenic budget

LHC beam screen chamber

Image currents with peaks up to 25 A will:

Generate an electric field

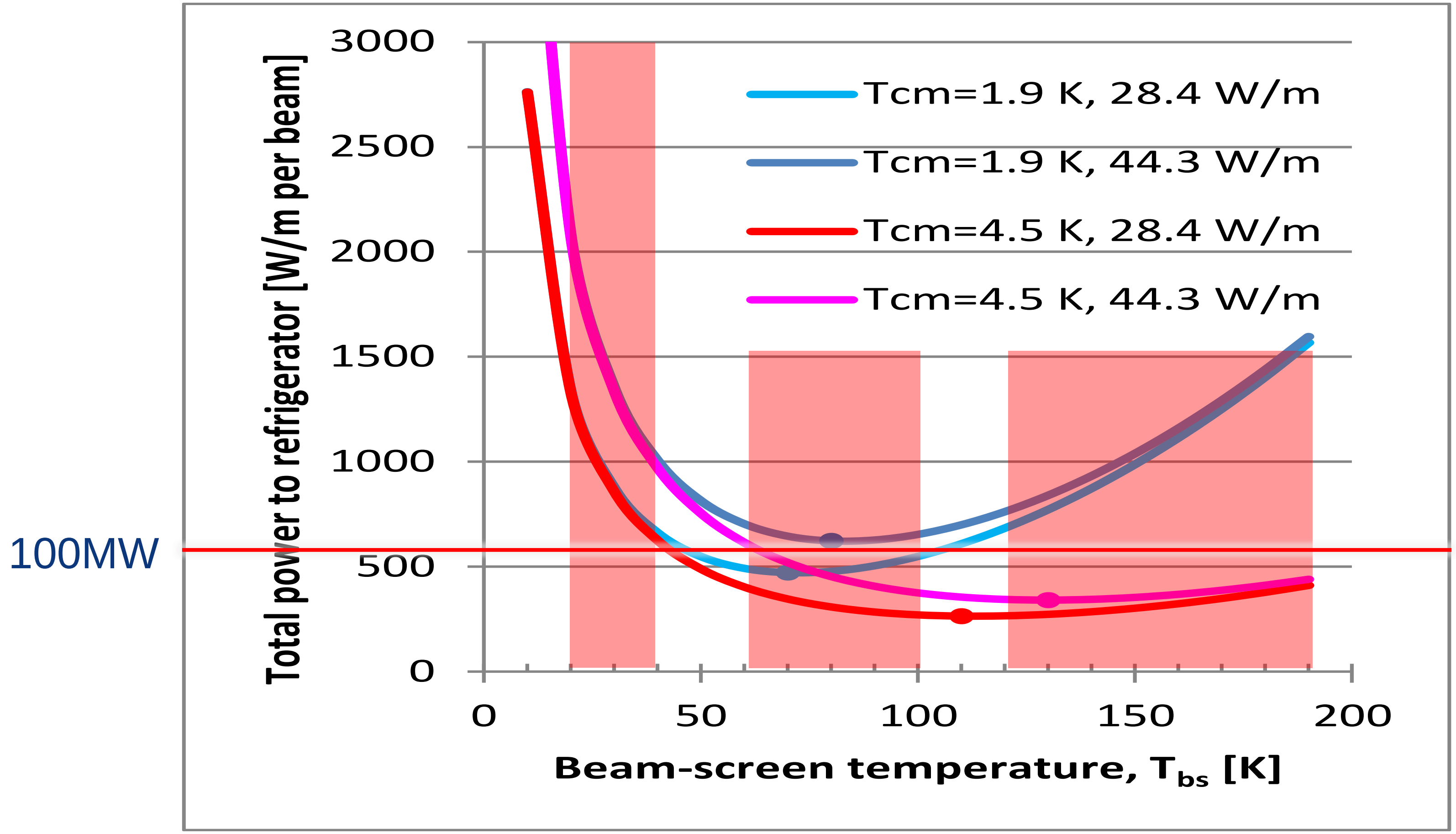
↓

Produce beam instabilities

Cu coated stainless steel operating at 4.2 K

The LHC solution is not viable for the FCC's beam screen chamber

In the FCC, assuming a chamber with a refrigeration efficiency like in the LHC



Limit the cryogenic load to 100 MW

⇩

Temperature range 40 – 60 K

Cu may not provide low enough surface impedance at this temperature range

We propose to substitute Cu for a $REBa_2Cu_3O_{7-x}$ coated conductor

Consortium

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Expertise in design, characterization and fabrication of CC integration of CC in superconducting devices

X. Granados, J. Gutierrez, T. Puig and A. Romanov

IFAE
Institut de Física d'Altes Energies
EXCELENCIA SEVERO OCHOA
BIST Barcelona Institute of Science and Technology

Expertise in instrumentation and a large engineering department

P. Gonzalez, I. Korolkov, R. Miquel

ALBA

Expertise in the design, construction and operation of complex accelerator infrastructure

P. Krkotic, F. Perez, M. Pont

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Expertise in RF measuring set up development for HTS superconductors

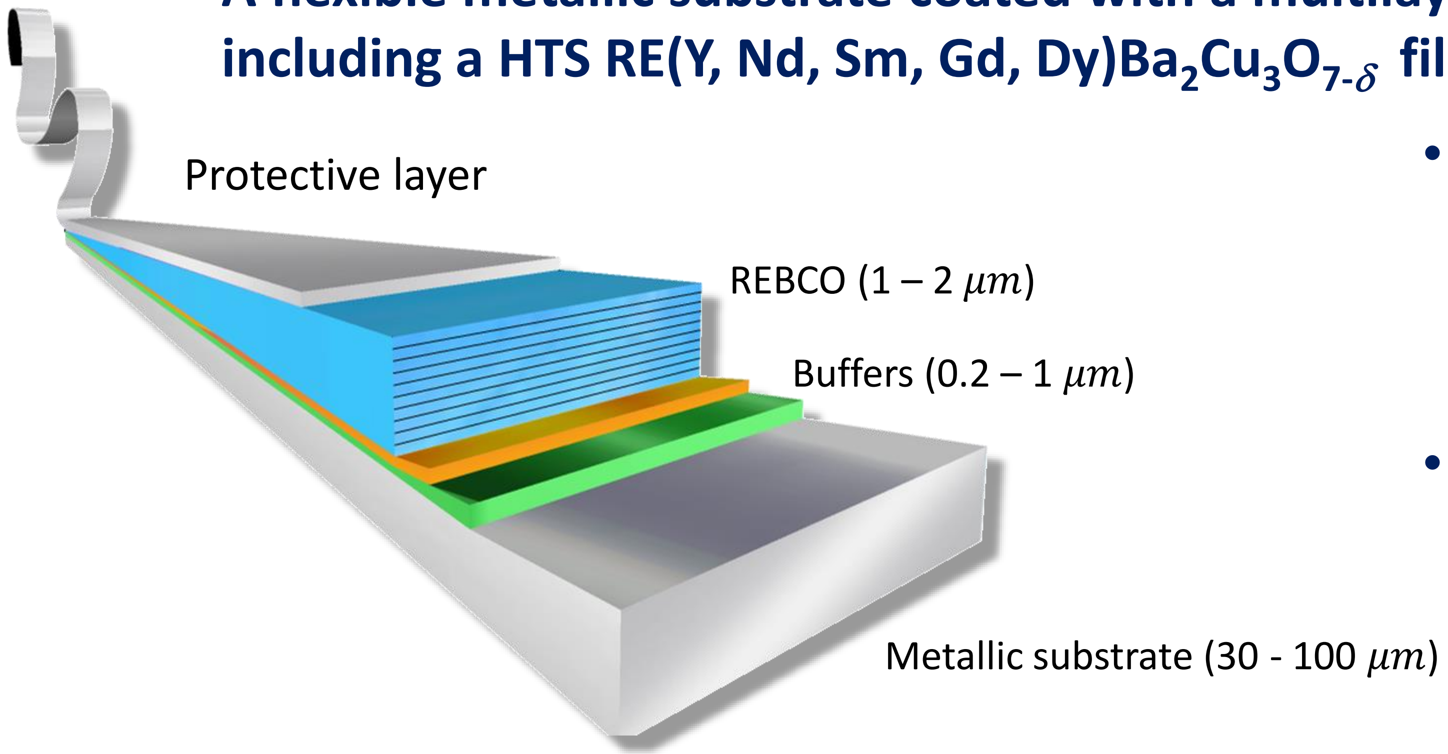
J. O'Callaghan

CERN

S. Calatroni, P. Chiggiato,
E. Garcia-Tabarés, M. Taborelli

Coated Conductors are a revolution in materials science and engineering

A flexible metallic substrate coated with a multilayer of epitaxial multifunctional oxide layers, including a HTS RE(Y, Nd, Sm, Gd, Dy)$Ba_2Cu_3O_{7-\delta}$ film…

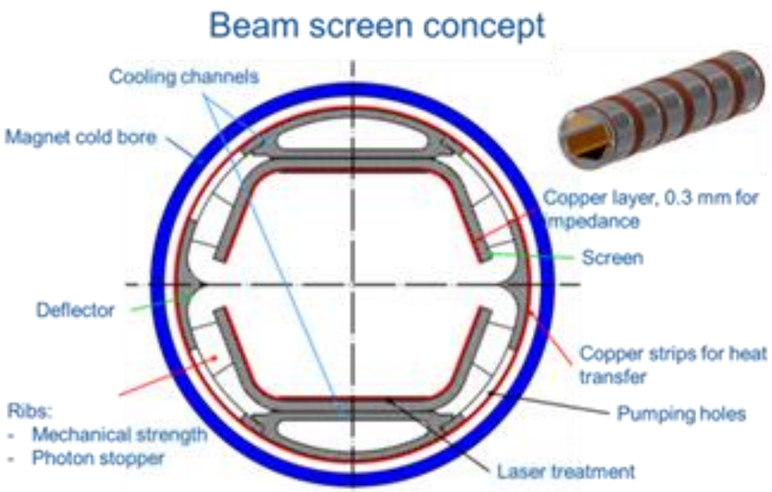


- **High degree of customization of the superconducting properties through tailoring of the microstructure.**
- **Capable of carrying 25 times higher current (DC) than the peak induced currents in the FCC.**

… scalable technology for growing km-length REBCO CC and is commercially available

Presently produced by American Superconductor, BRUKER, Fujikura, SuNAM, SuperOx, SuperPower (A Furukawa Company), STI, THEVA, Shanghai 上海超导, OXOLUTIA, deutsche nanoschicht, MetOx

Objectives



Evaluate the possibilities to use REBCO CC as low surface impedance material in the FCC beam screen chamber

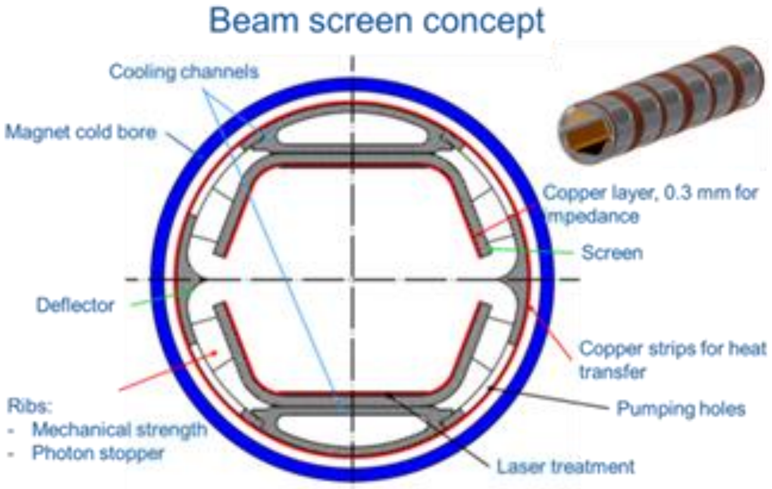
1 – Development and measurements of R_{sf} (H,T) and synchrotron radiation effect

2 – Evaluate beam instabilities (SEY, outgassing, persistent currents, life cycle)

3 – Define CC characteristics: Architecture, thickness, $I_c(H,T)$ microstructure, covering layer, ….

4 – Welding and assembling technology and evaluation of mechanical properties, vacuum compatibility and heat transport characteristics

Objectives



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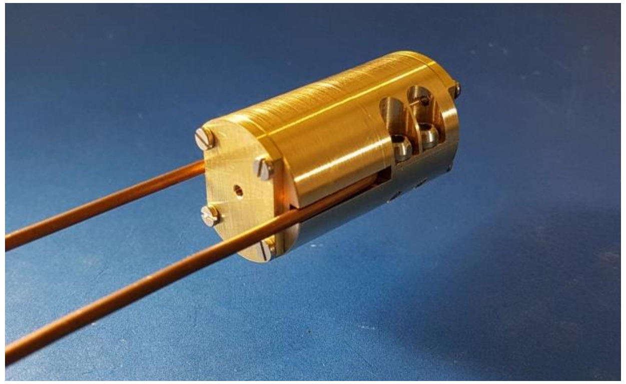
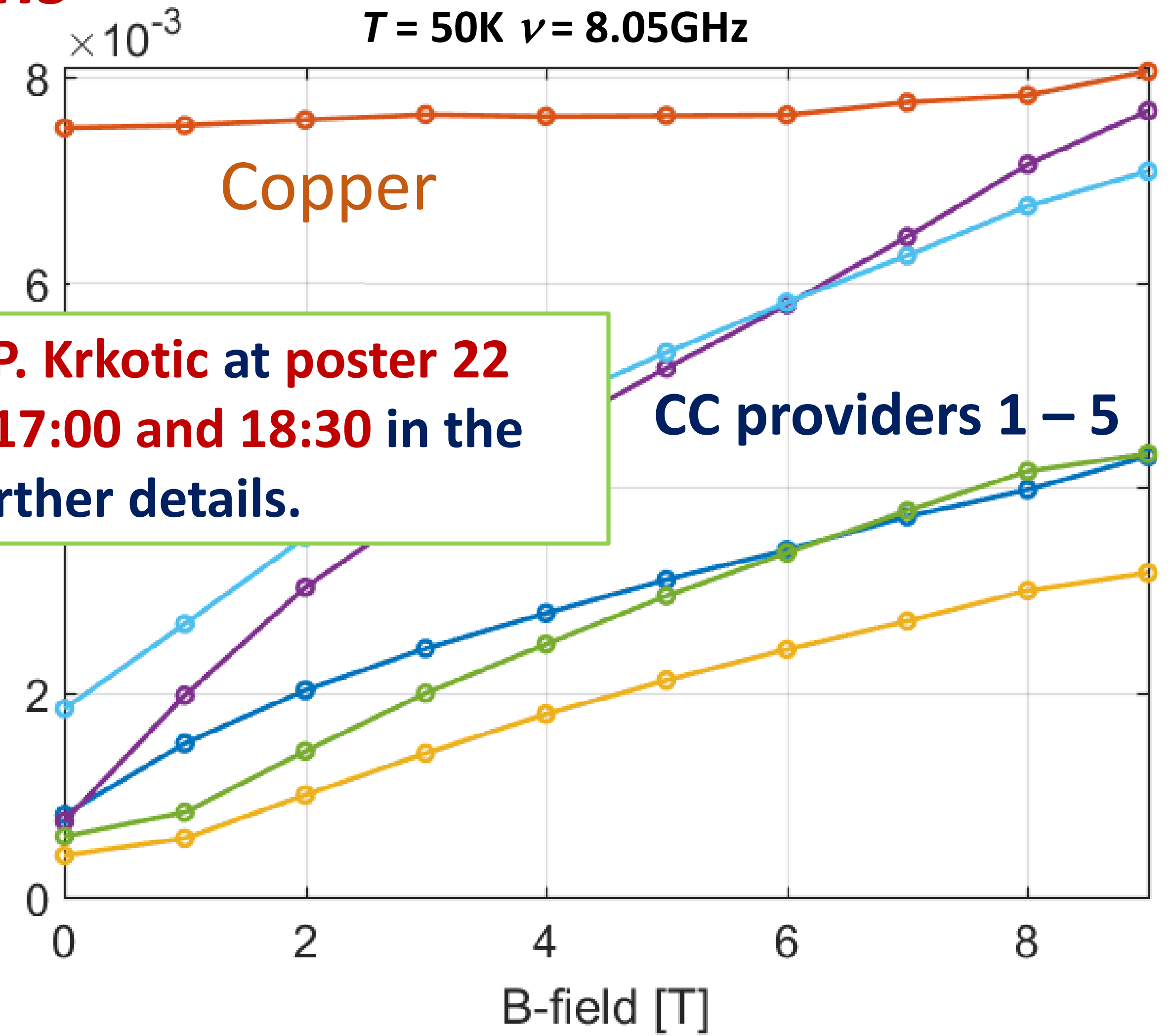
REBCO CCs show the potential to outperform Cu under the FCC working conditions



In house developed 8.05 GHz cavity resonator compatible with 25mm bore 9 T magnet at ICMAB



Please visit Mr. P. Krkotic at poster 22 today between 17:00 and 18:30 in the grote zaal for further details.

"Non-optimized" REBCO CCs outperform Cu at 50K and up to 9T

R_S is microstructure dependent

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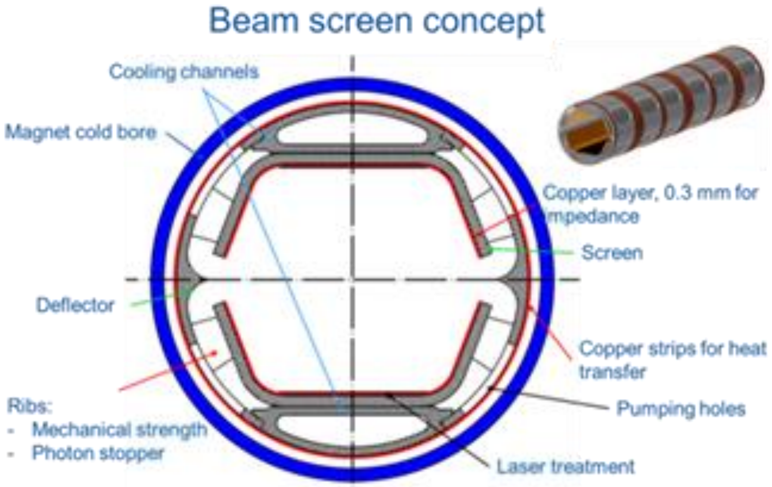

Beam screen concept

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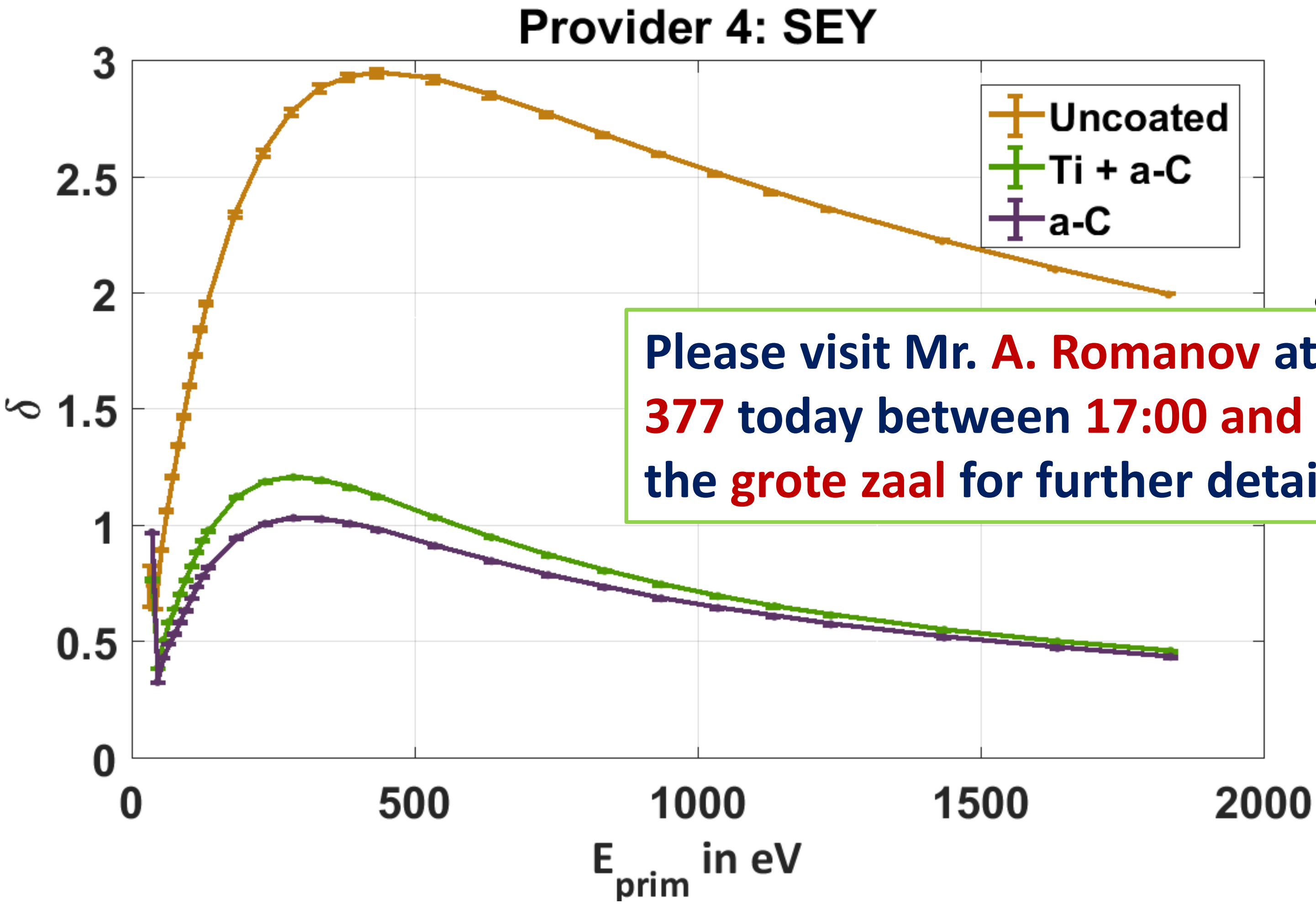
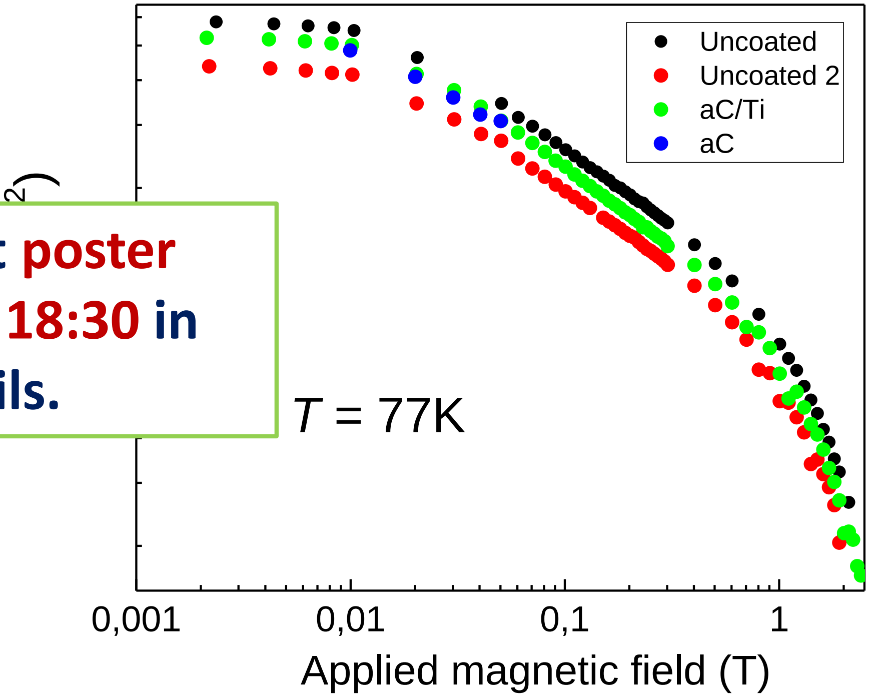
Amorphous carbon coating as protective layer with low SEY



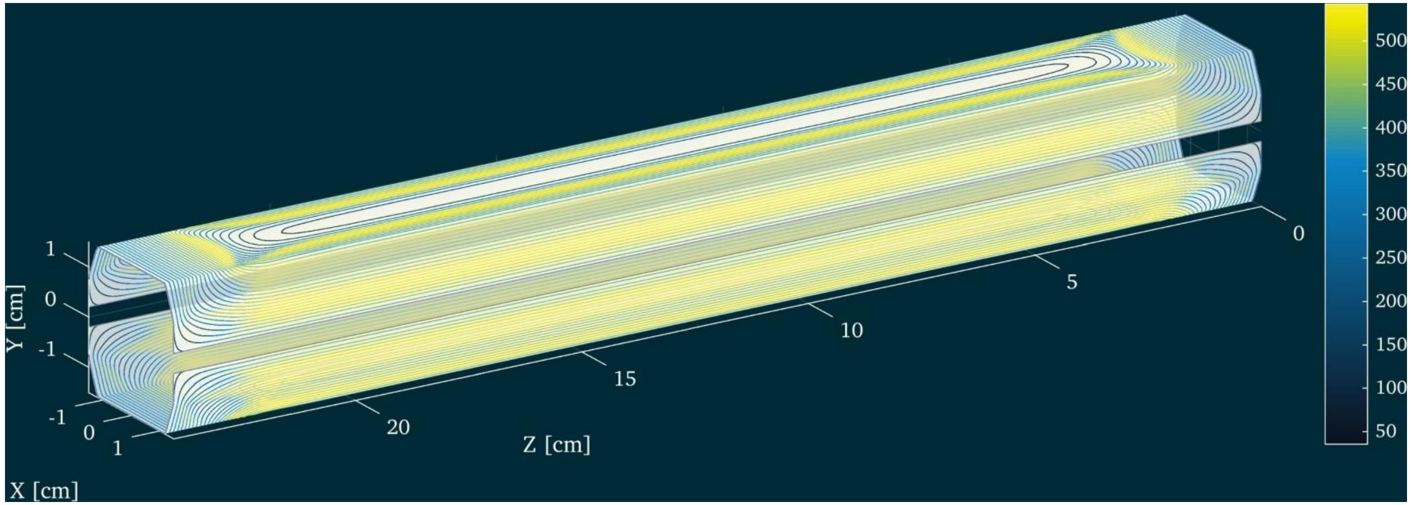


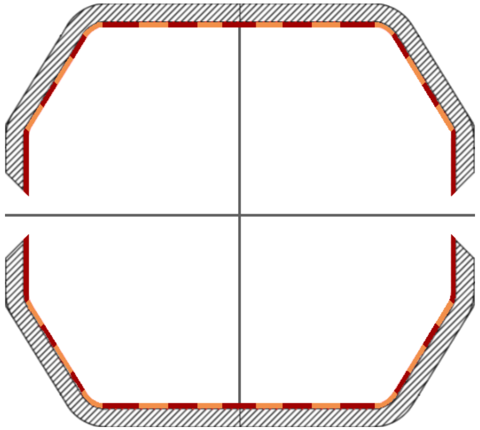
Please visit Mr. A. Romanov at poster 377 today between 17:00 and 18:30 in the grote zaal for further details.

Amorphous carbon is compatible with REBCO and lowers the SEY ~1

Striated configuration to minimize trapped fields

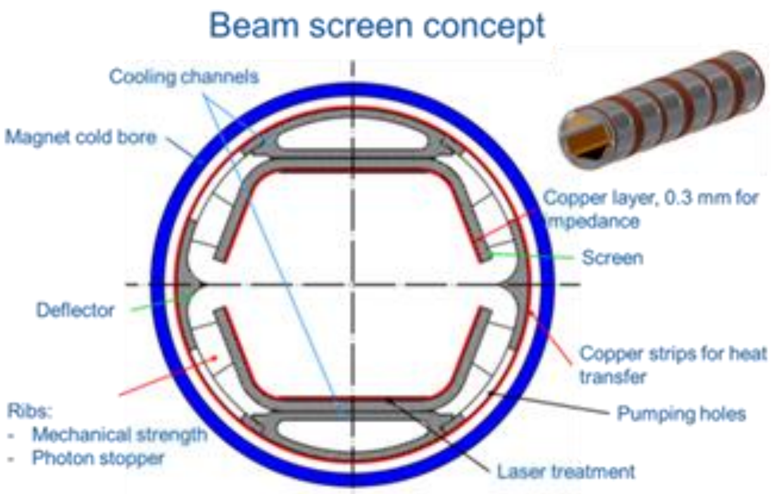
Screening currents during magnetic field ramping will produce unacceptable field quality effects





Simulations have shown that a striated geometry will drastically reduce trapped magnetic fields in the superconductor, recovering acceptable levels of field quality during ramping

Objectives



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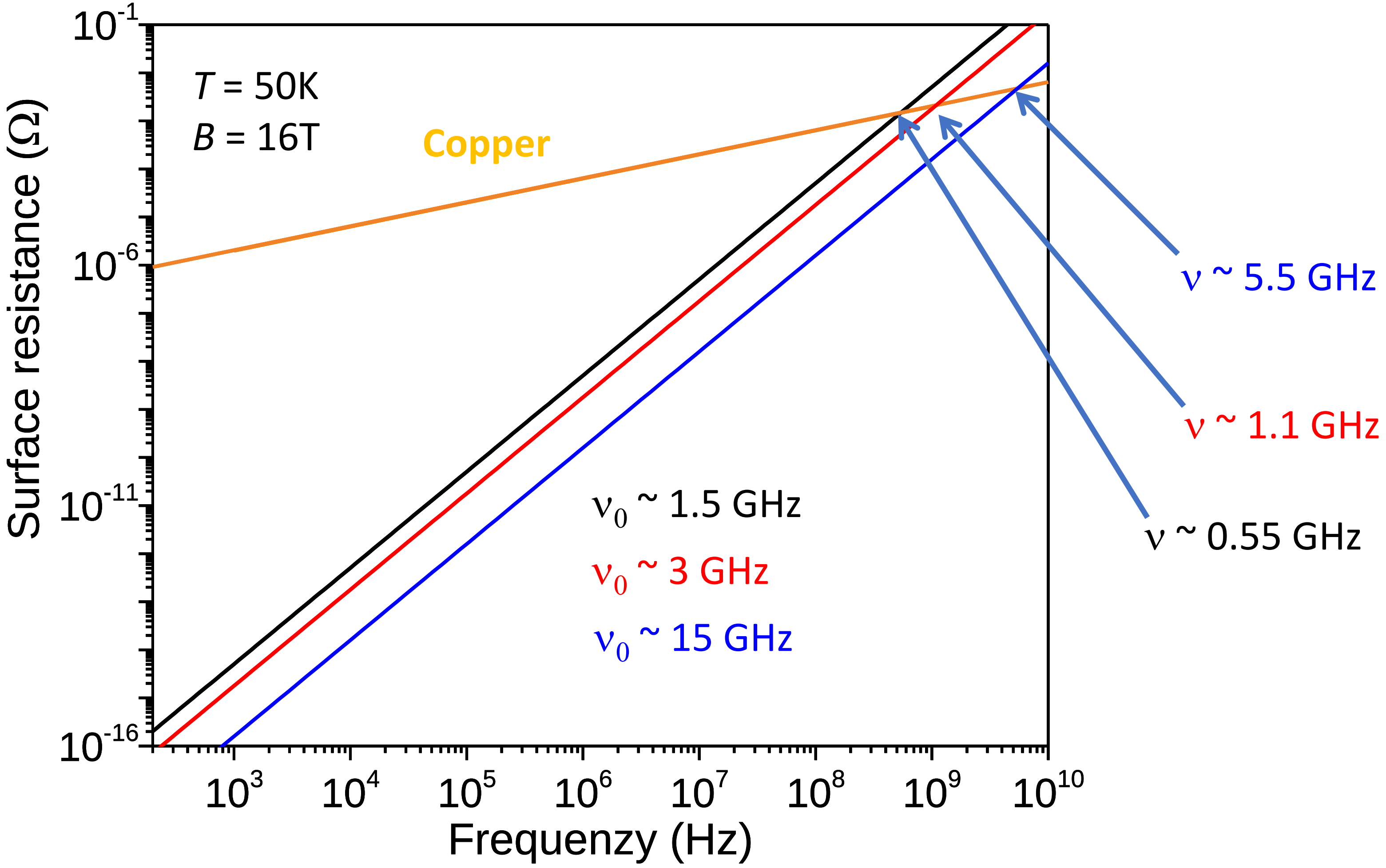
Depinning frequency is the most relevant factor determining the R_s of REBCO

Sergio Calatroni and Ruggero Vaglio, IEEE Transactions on Applied Superconductivity 27, 2017

Within the rigid-fluxon model under the FCC conditions

$$R_{sf} = \frac{R_n}{\sqrt{2}}\sqrt{\frac{B}{B_{irr}}}\left(\frac{\omega}{\omega_0}\right)^{3/2}$$



At ICMAB we are in position to do an in house study to optimize the microstructure

REBCO microstructure allows to tune the superconducting properties for specific working conditions

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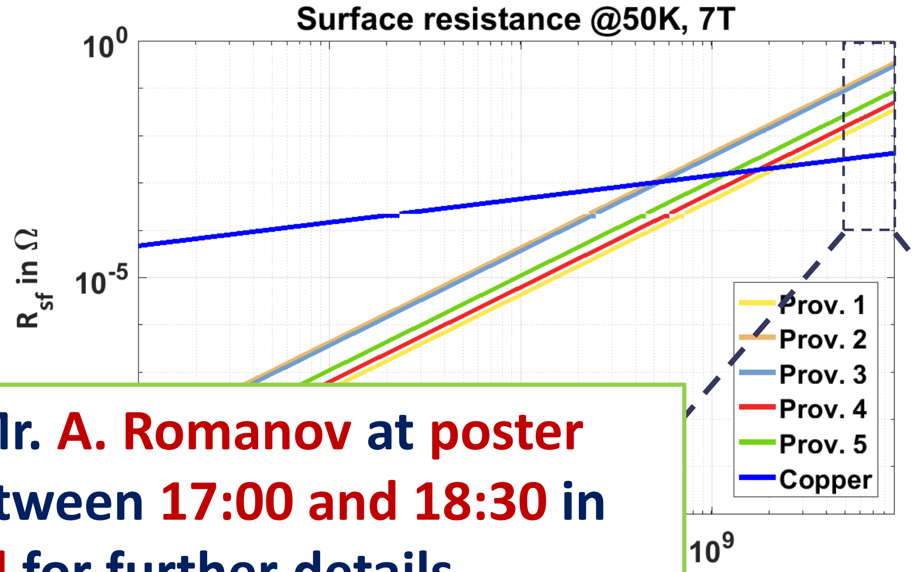
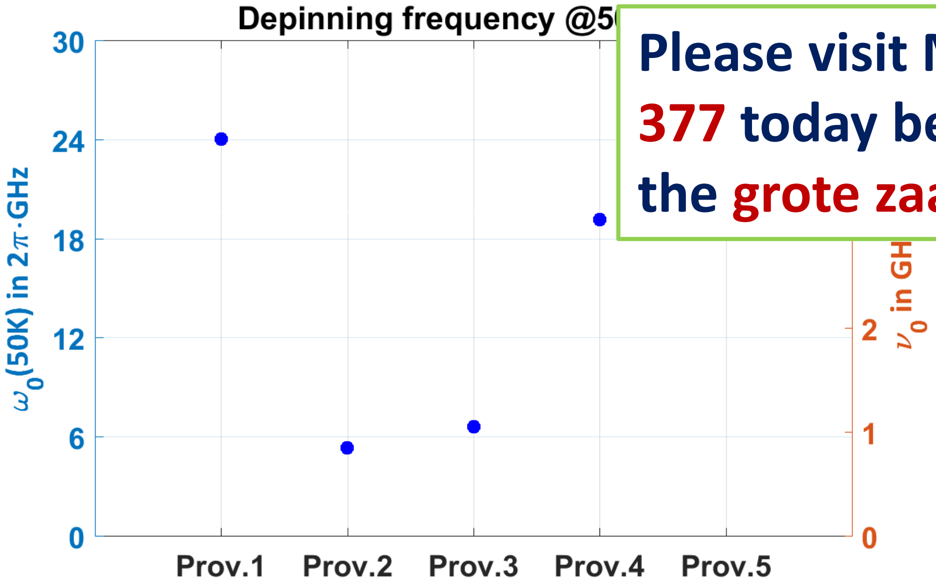
$$\omega_0(B) = 2\pi \frac{\rho_n J_c(T,B)}{B_{irr}} \sqrt{\frac{B}{\phi_0}}$$





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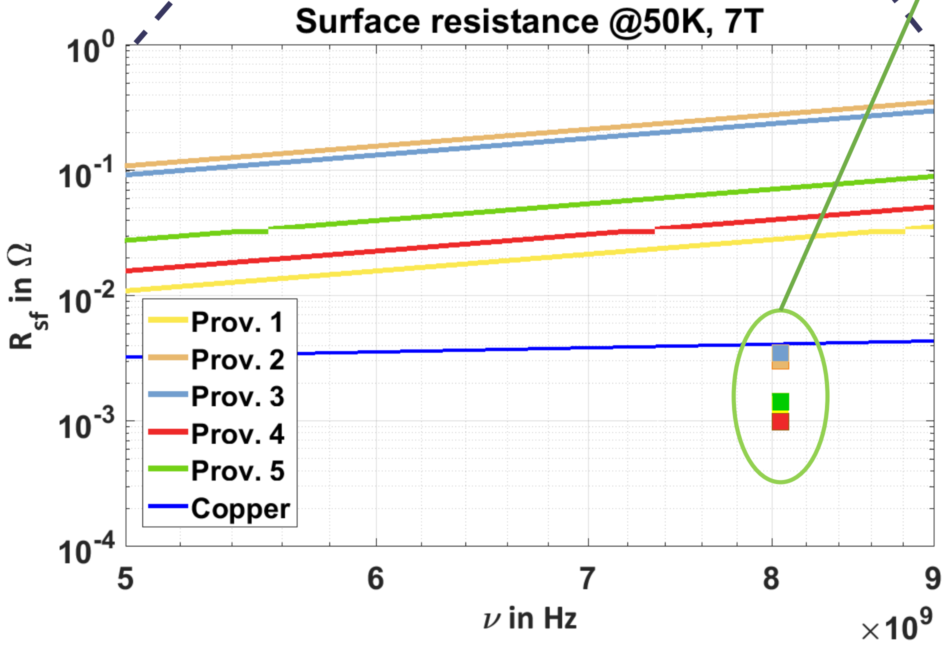


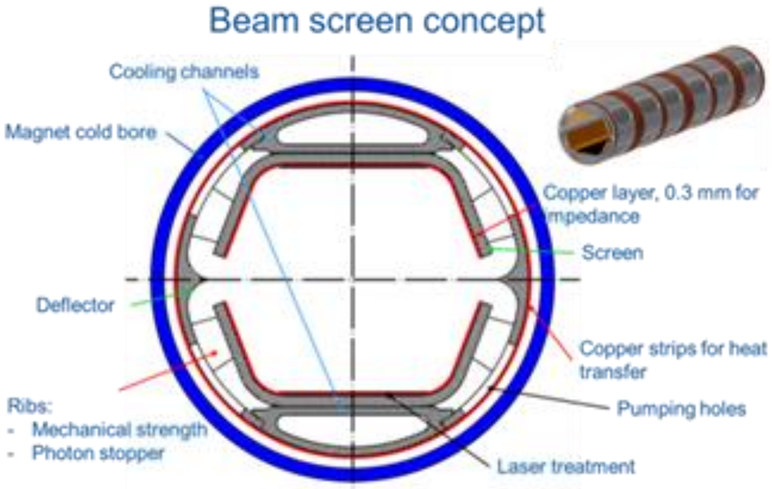
Experimental data

ω_0 scales with experimental R_s

The rigid-fluxon model overestimates REBCO's R_s

By tunning microstructure → optimize ρ_n, J_c and B_{irr} to maximize ω_0 and minimize $R_s(H,T)$

Objectives



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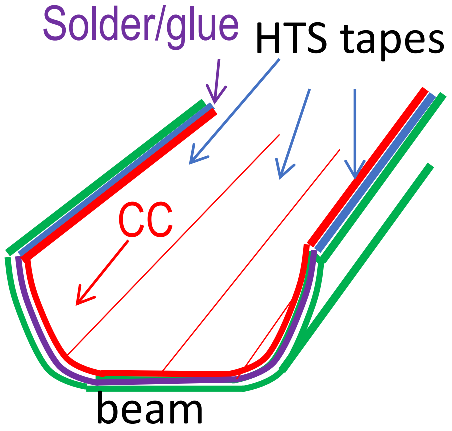
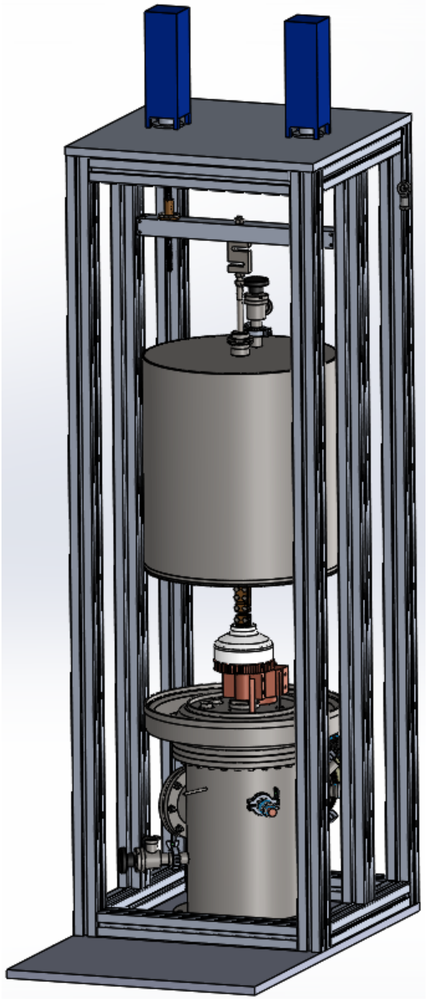
Welding and mechanical tests of aC/REBCO/Steel stacks under final steps of development

Solders based on Sn / Pb / Cu / Bi & In will be tested at temperatures < 220ºC





An experimental system to assess 2D /3D stress maps based in optical image correlation with in situ monitoring the I_c is under its final steps of construction

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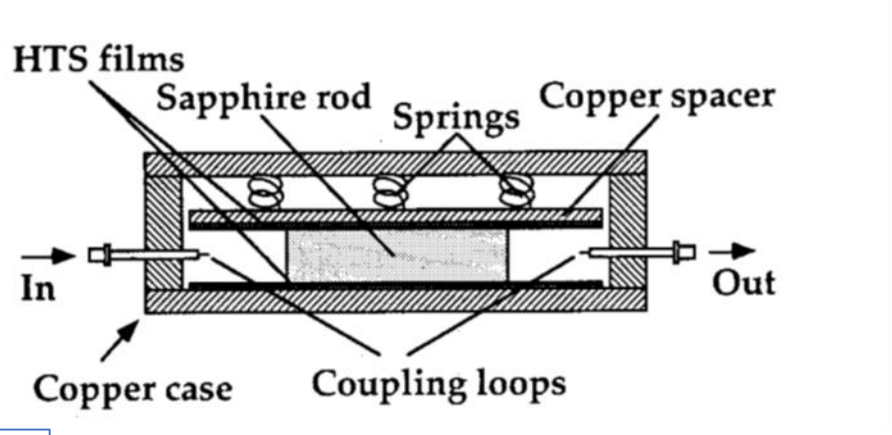
Conclusions

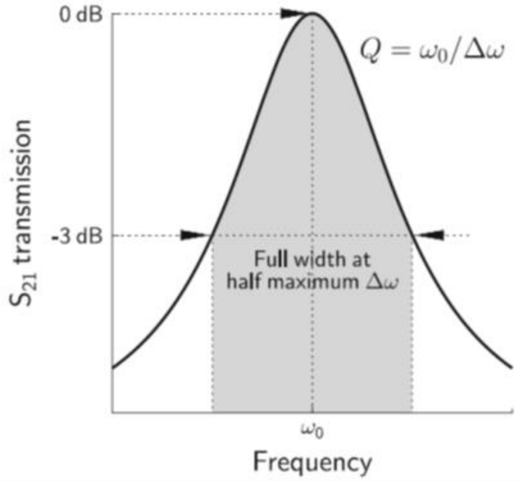
- REBCO CC are being positively validated as a solution for the FCC’s beam screen chamber
- All studied REBCO manufacturers perform better than Cu at 50K and 9T at 8GHz
- aC and Ti/aC coatings are compatible with REBCO and reduce SEY to acceptable levels
- ω_0 allows us to relate R_s to microstructre

Outlook

- Construct the 1 GHz resonator (already designed) compatible with 25 mm bore magnet and assess REBCO R_s aut 50K, 16T and under synchrotron radiation
- Assess aC coating performance as a protective layer for REBCO
- Start welding and mechanical tests on ac /REBCO/Steel and aC/Ti/REBCO/Steel stacks with low persistent current geometries
- Optimize REBCO microstructure to minimize R_s

Resonator





$$\boxed{R_s = \sqrt{\pi f \mu \rho}}$$

$$\frac{1}{Q} = \overbrace{\frac{Rs\_up}{Gup} + \frac{Rs\_down}{Gdown}}^{R_s} + \frac{Rs\_side}{Gside} + p \cdot tan\delta \longrightarrow Resonator\ loses$$

$$\longrightarrow Geometrical\ factors$$