SRF Material Options for FCC

Sarah Aull

on behalf of the

FCC RF & WP3 Working Group

Cryogenic Consumption of FCC-ee

Cryogenic power consumption is one of the cost drivers in a CW machine, in particular for FCC-ee

$$P_{cryo,grid} \sim \frac{V^2}{R/_Q} \frac{1}{Q_0} \sim R_S\,(f, T, \ell, E_{acc})$$

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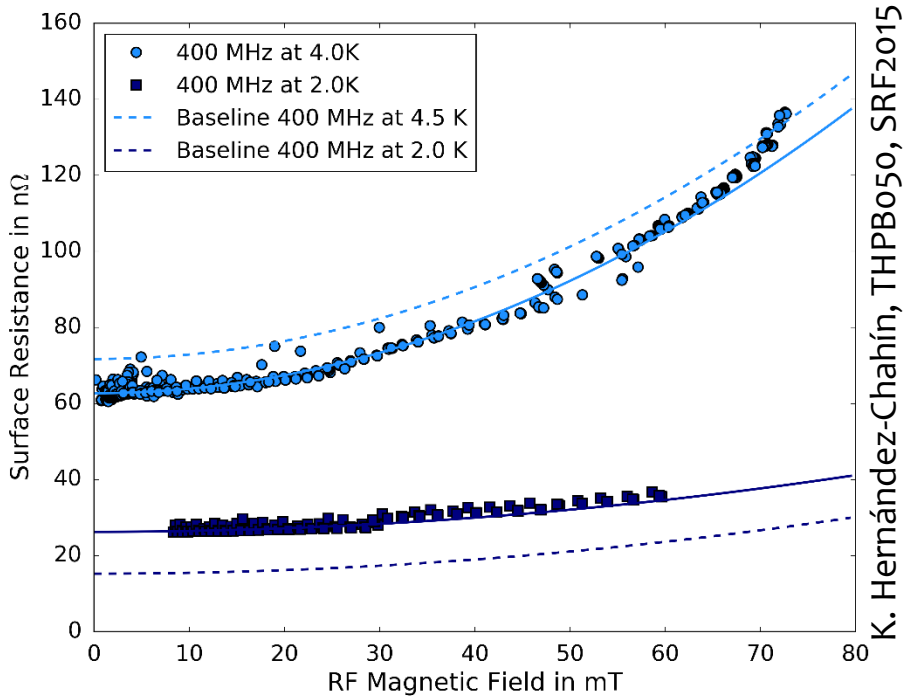
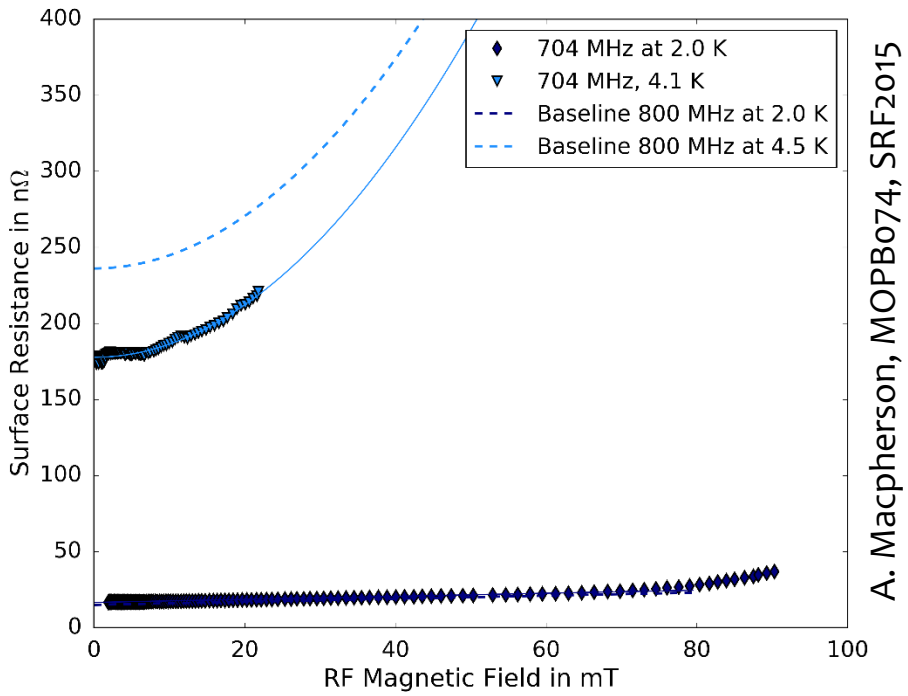
Material

- Collect representative $R_S(f, T, \ell, E_{acc})$ data
- Define baseline performance
- Calculate the cryogenic consumption for each (material, frequency, temperature, field)–combination

Bulk Niobium
A Well-Known Technology



K. Hernández-Chahín, THPB050, SRF2015



A. Macpherson, MOPB074, SRF2015

High level of expertise

high gradients

High cost for raw material

Requires magnetic shielding

Only operation at < 2.1 K

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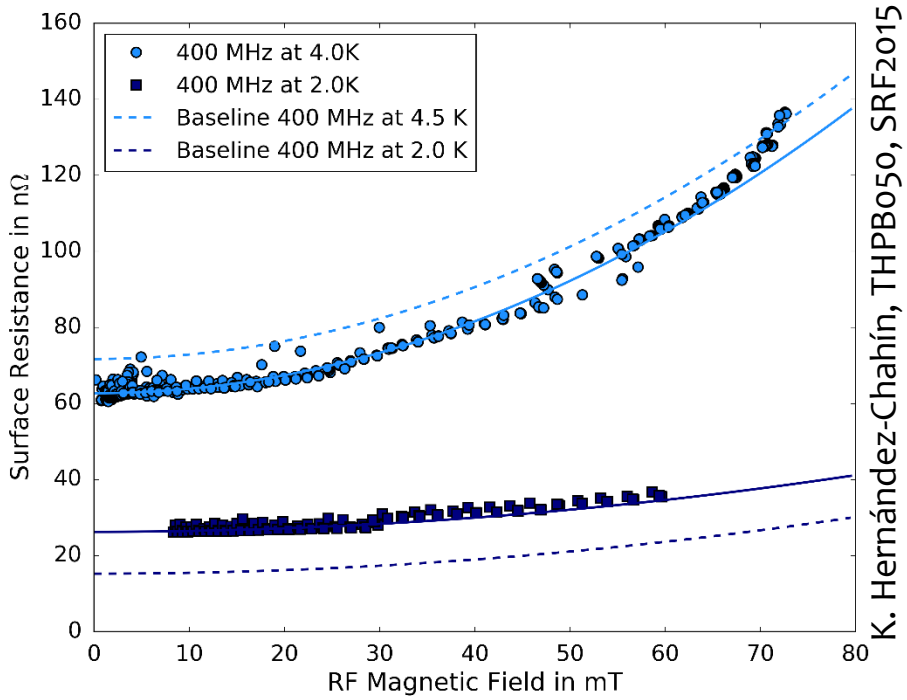
Collaboration with FNAL to explore potential of N doping at lower frequencies and 4.5 K operation.



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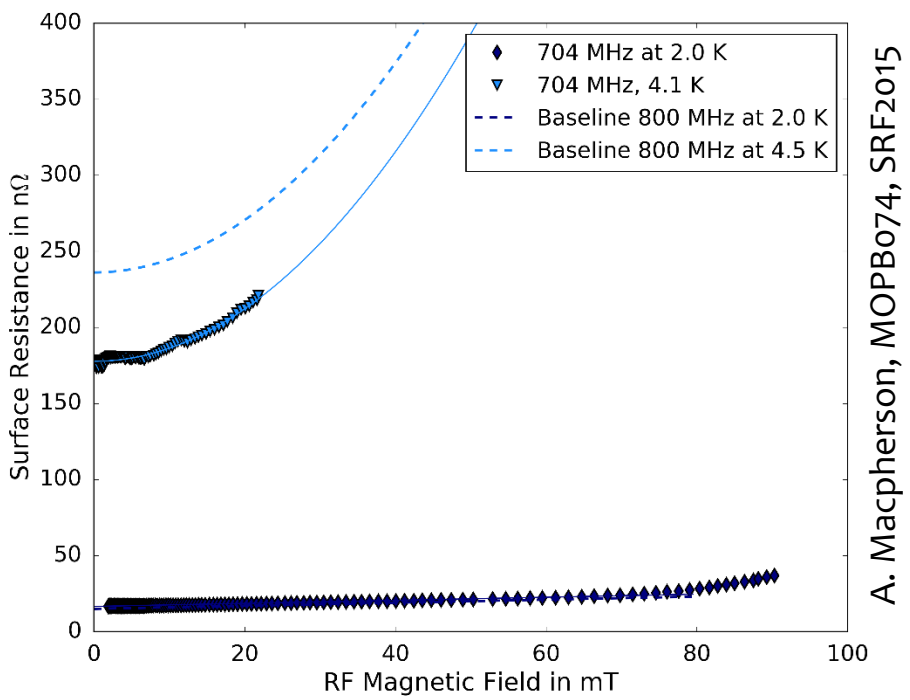

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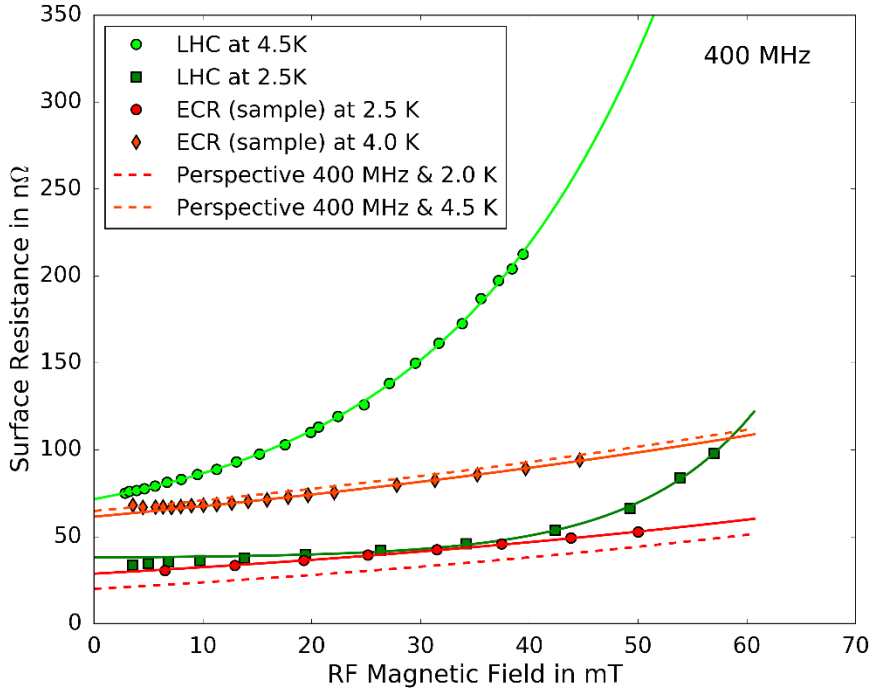
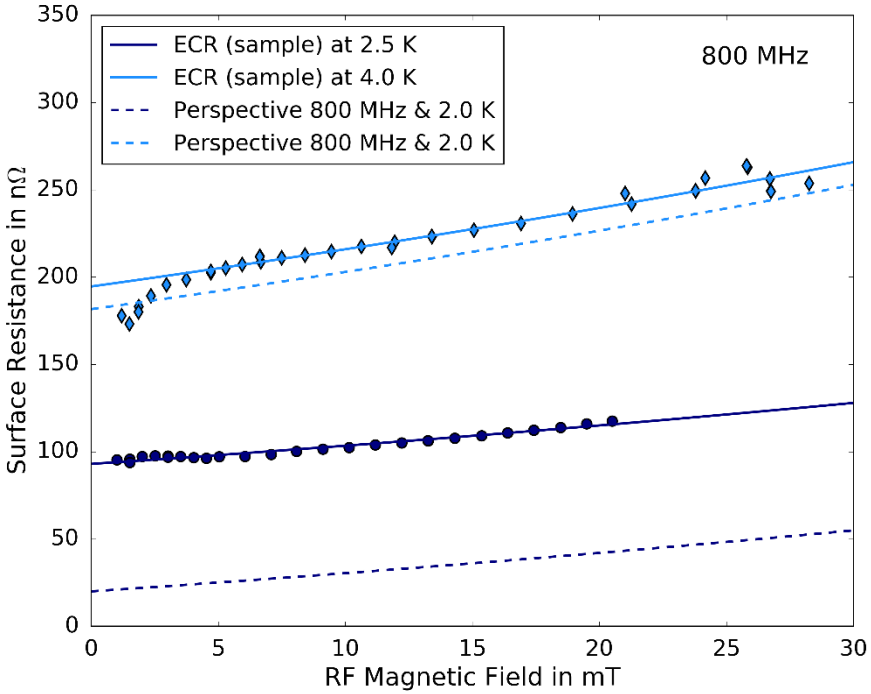




Lower raw material costs

High thermal stability

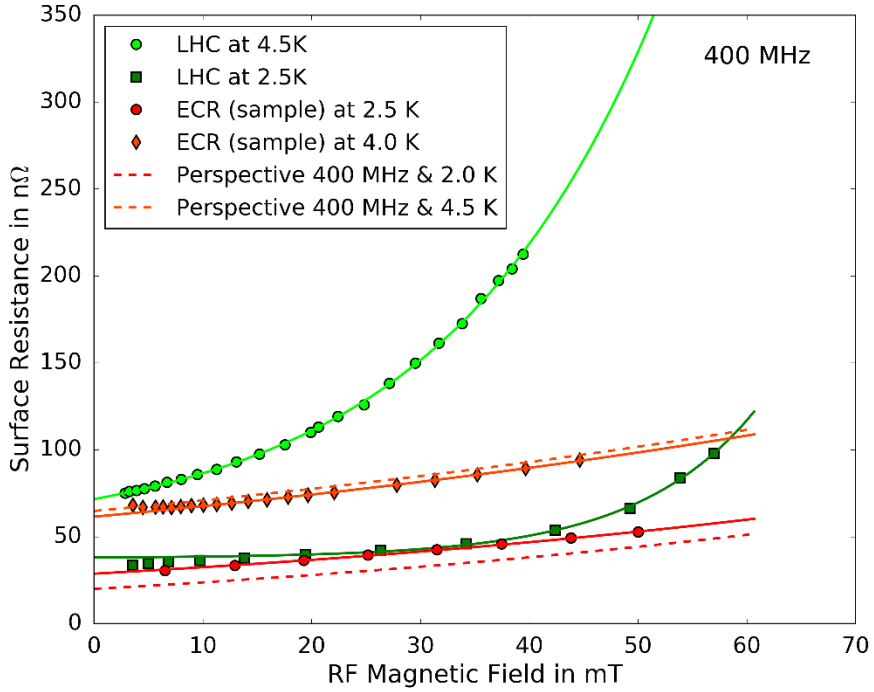
No magnetic shielding

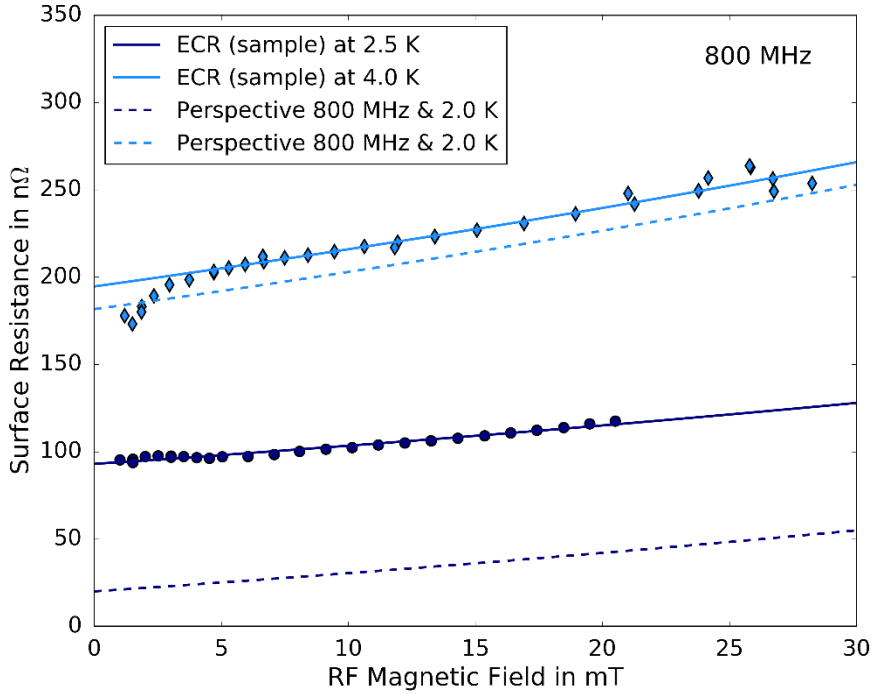
Only low E_{acc} due to strong Q-Slope

Mitigated Q-Slope for energetic condensation techniques

Nb/Cu
Energetic Condensation Techniques

Nb/Cu R&D on 1.3 GHz cavities at CERN; and in collaboration with LNL and STFC





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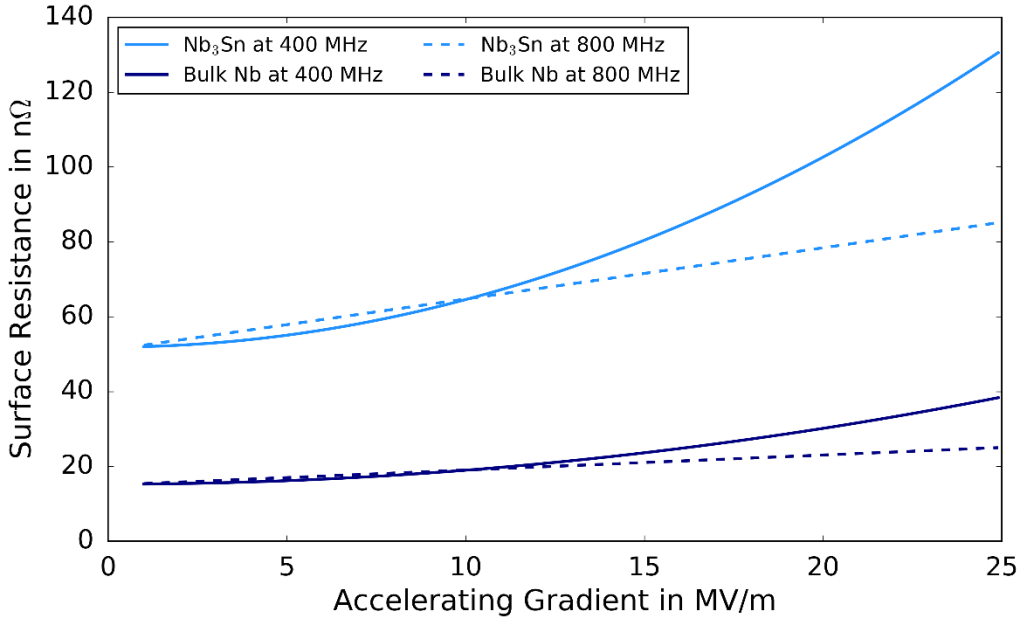
Beyond Niobium: Nb3Sn
Minimum Performance Target

Higher carnot efficiency at 4.5 K

+

Higher technical efficiency at 4.5 K

Lower cryogenic consumption than bulk niobium at 2 K for $R_s(Nb_3Sn@4.5K) < 50\ n\Omega$



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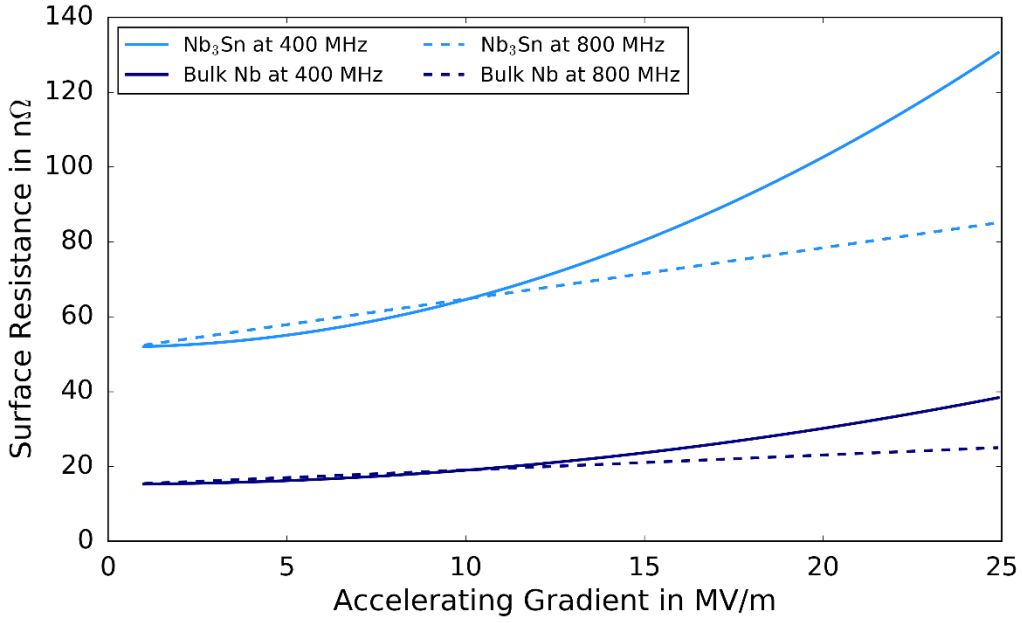
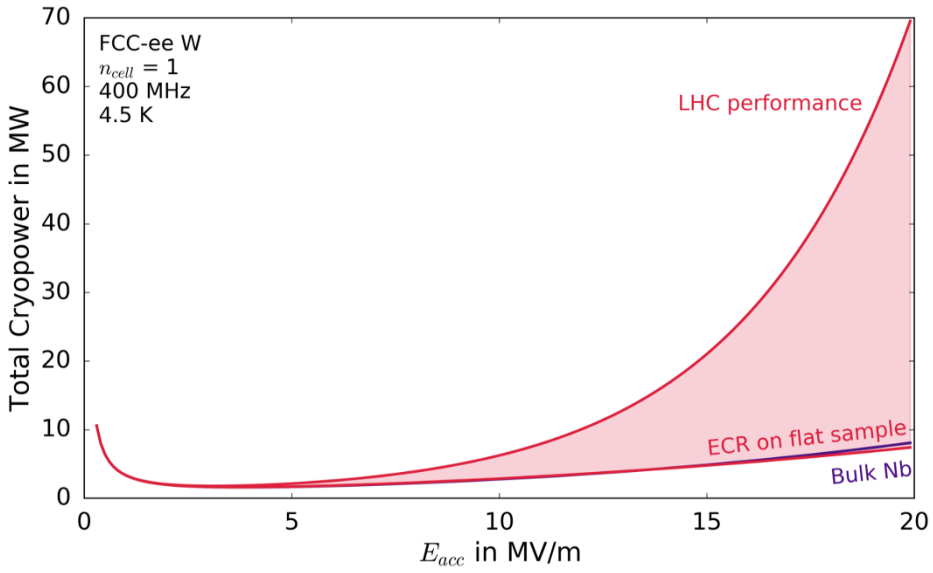


Details about the A15 R&D program: Alternative materials and coating techniques for cavities, K. Ilyina (CERN)

RF requirement for FCC-ee W



	OPTION 1	OPTION 2
Frequency in MHz	400	400
Technology	Nb/Cu	Bulk Nb
E_{acc} in MV/m	10	
Temperature in K	4.5	2.0
# of cells/cavity	1 – 4	
# of cavities FCC W	428 – 108	
# of CM for FCC W	108 – 28	

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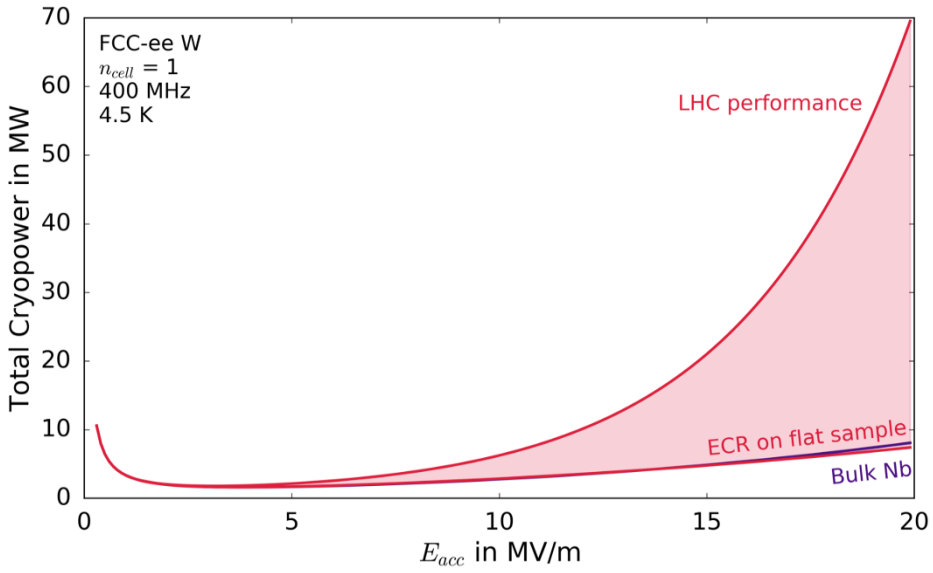

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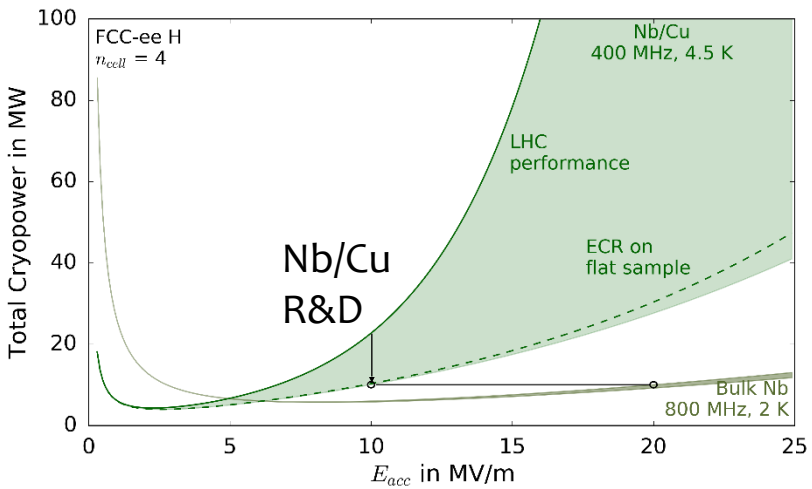
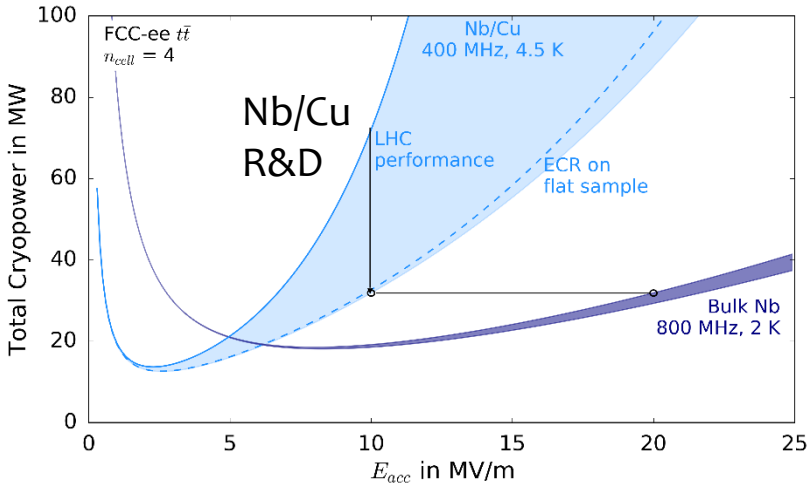
Nb/Cu is the material of choice for FCC-ee W

Number of cells to be determined by machine impedance considerations and staging scenarios

RF requirement for FCC-ee Higgs & top



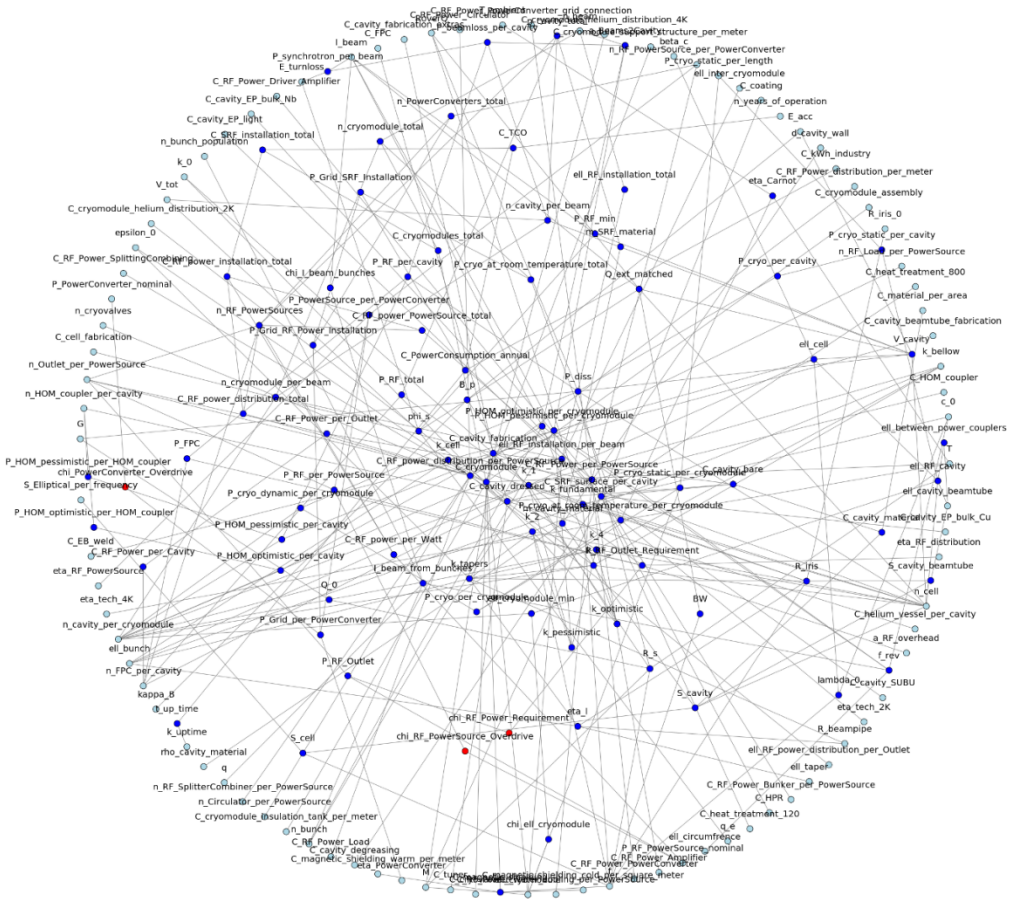


	OPTION 1	OPTION 2
Frequency in MHz	400	800
Technology	Nb/Cu	Bulk Nb
E_{acc} in MV/m	10	20
Temperature in K	4.5	2.0
# of cells/cavity	3 – 5	
# of cavities FCC H	534 – 322	
# of cavities FCC t	846 – 508	
# of CM for FCC H	134 – 82	
# of CM for FCC t	212 – 127	

Two competing options for the SRF system for FCC-ee $t\bar{t}$

RF Model
Cost Estimate

RF scenarios and parameters layout for FCC
N. Schwerg (CERN)



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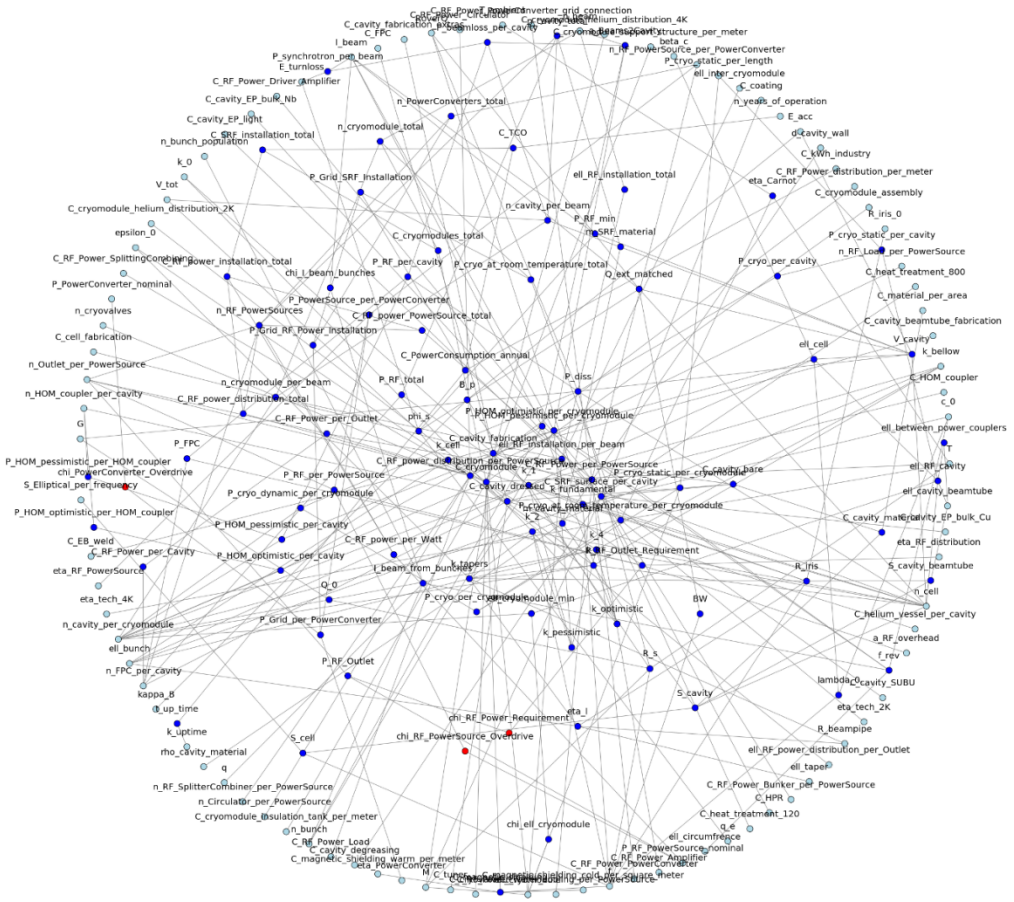

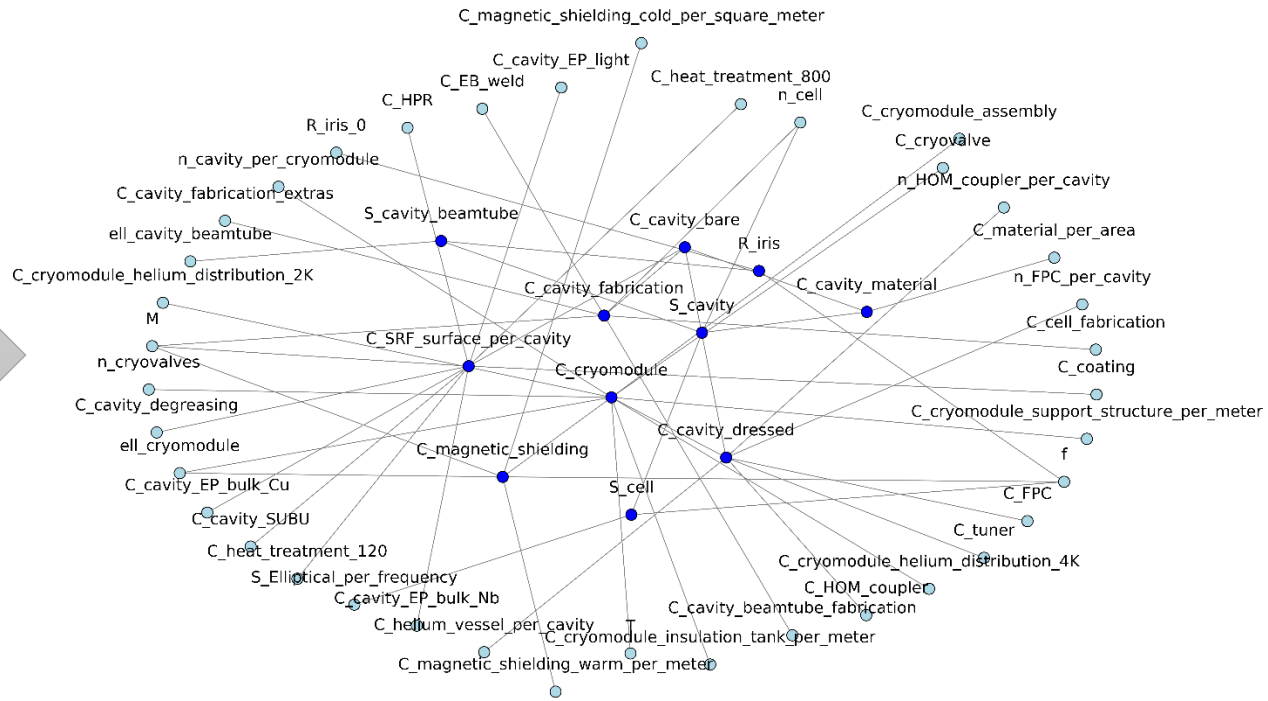

Production Cost
from Sheet to Bare Cavity

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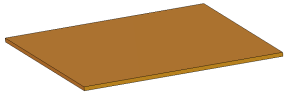

Raw Material (1/m²)

400 MHz & 4 cells

Cavity Size

800 MHz & 4 cells

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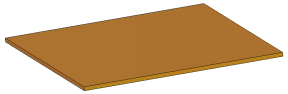

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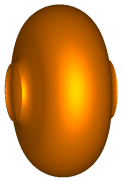
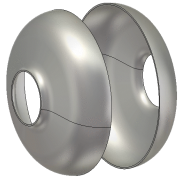


Spinning of seamless cells

Fabrication of a cell

Deep drawing of half cells



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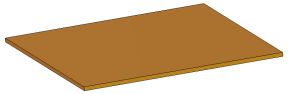

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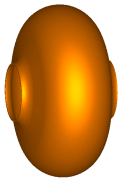

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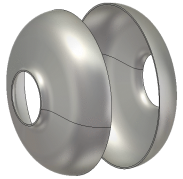
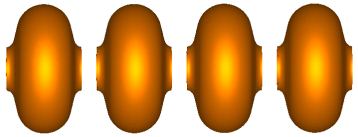
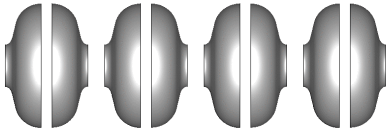




Electron Beam Welding of the cavity cells



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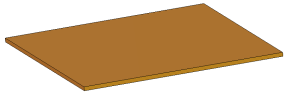

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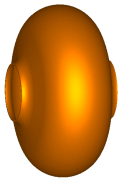

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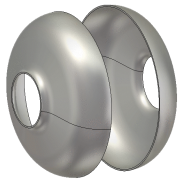

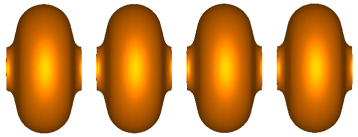

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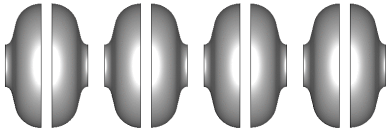
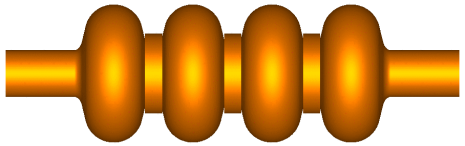
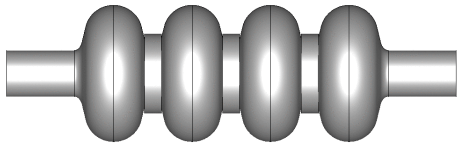




Electron Beam Welding of stiffening rings and beam tubes



Production Cost
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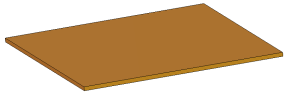

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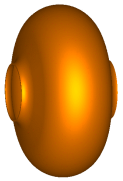

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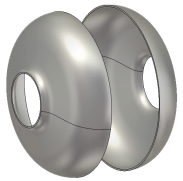

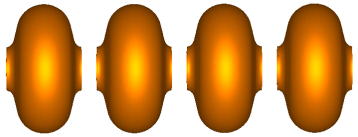

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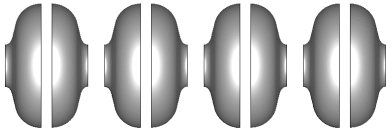

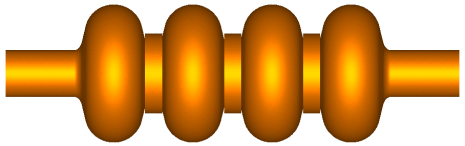

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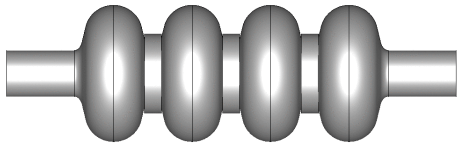
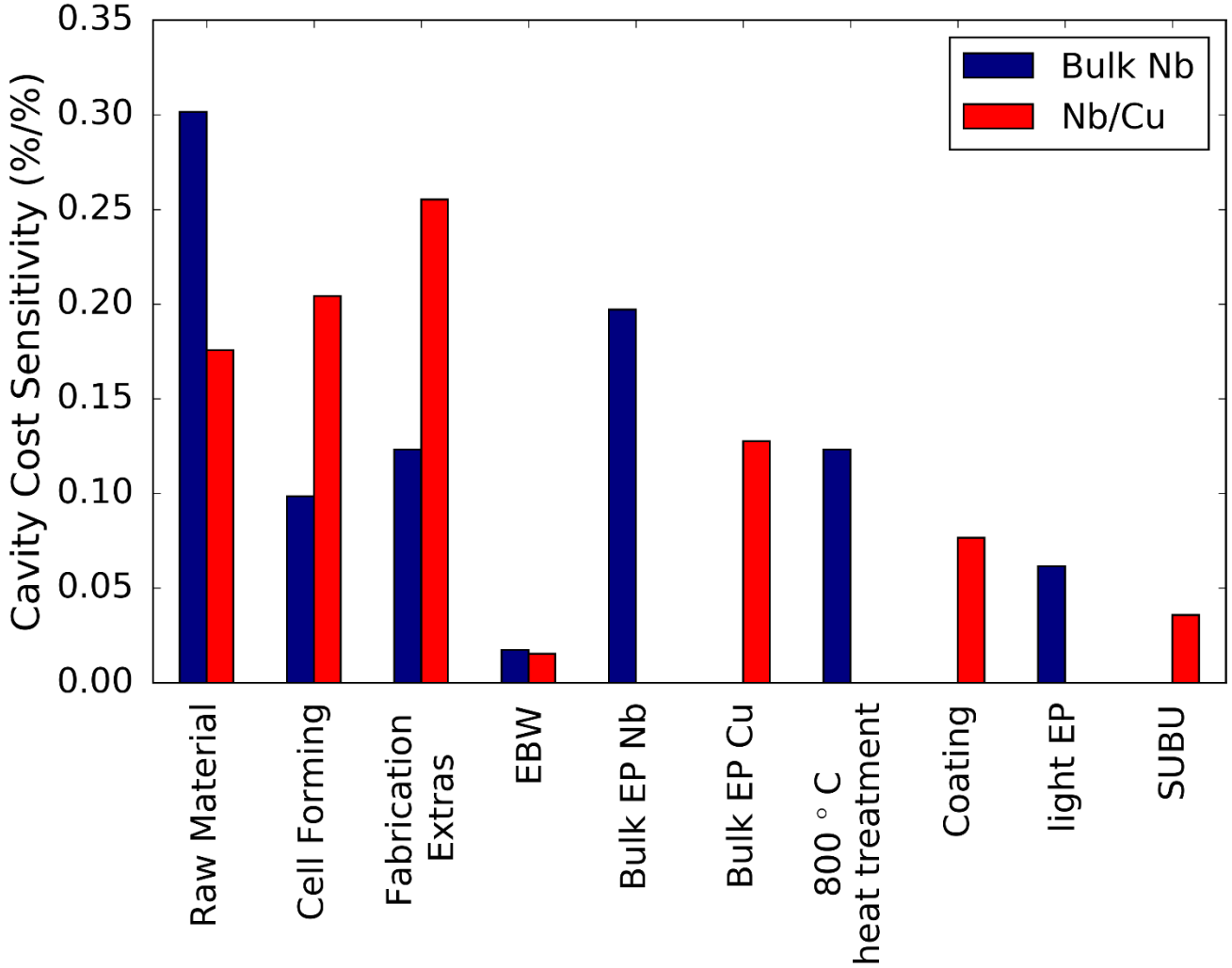


Bulk EP + Light SUBU + Coating

Chemical & Heat Treatments

Bulk EP + 800 °C + Light EP

Bare Cavity
Sensitivity to Production Cost



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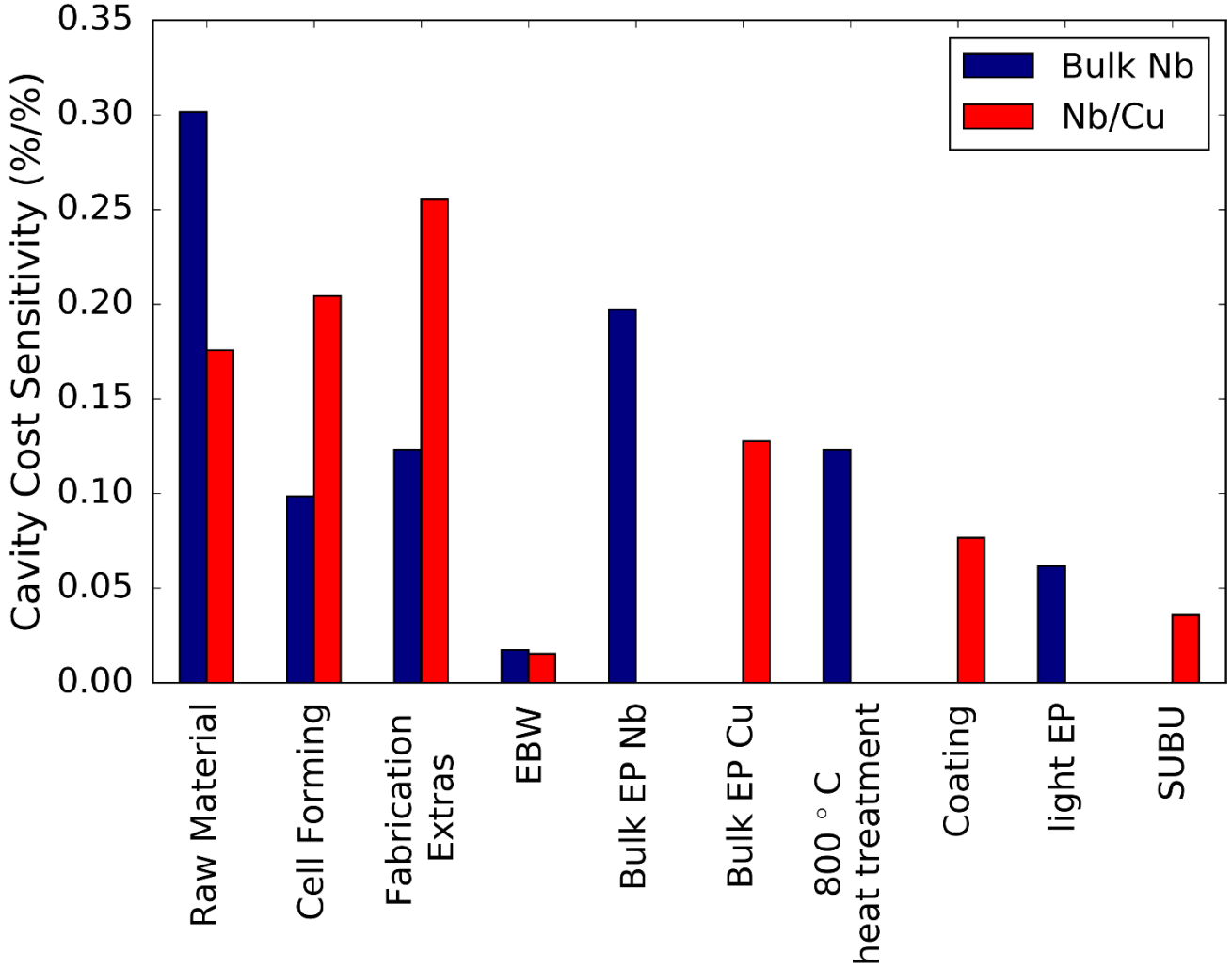
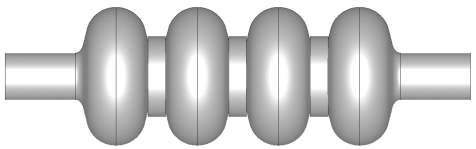
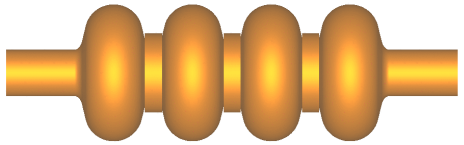


- Cost driver for bulk Nb cavities:
  - Raw material
  - Surface treatments



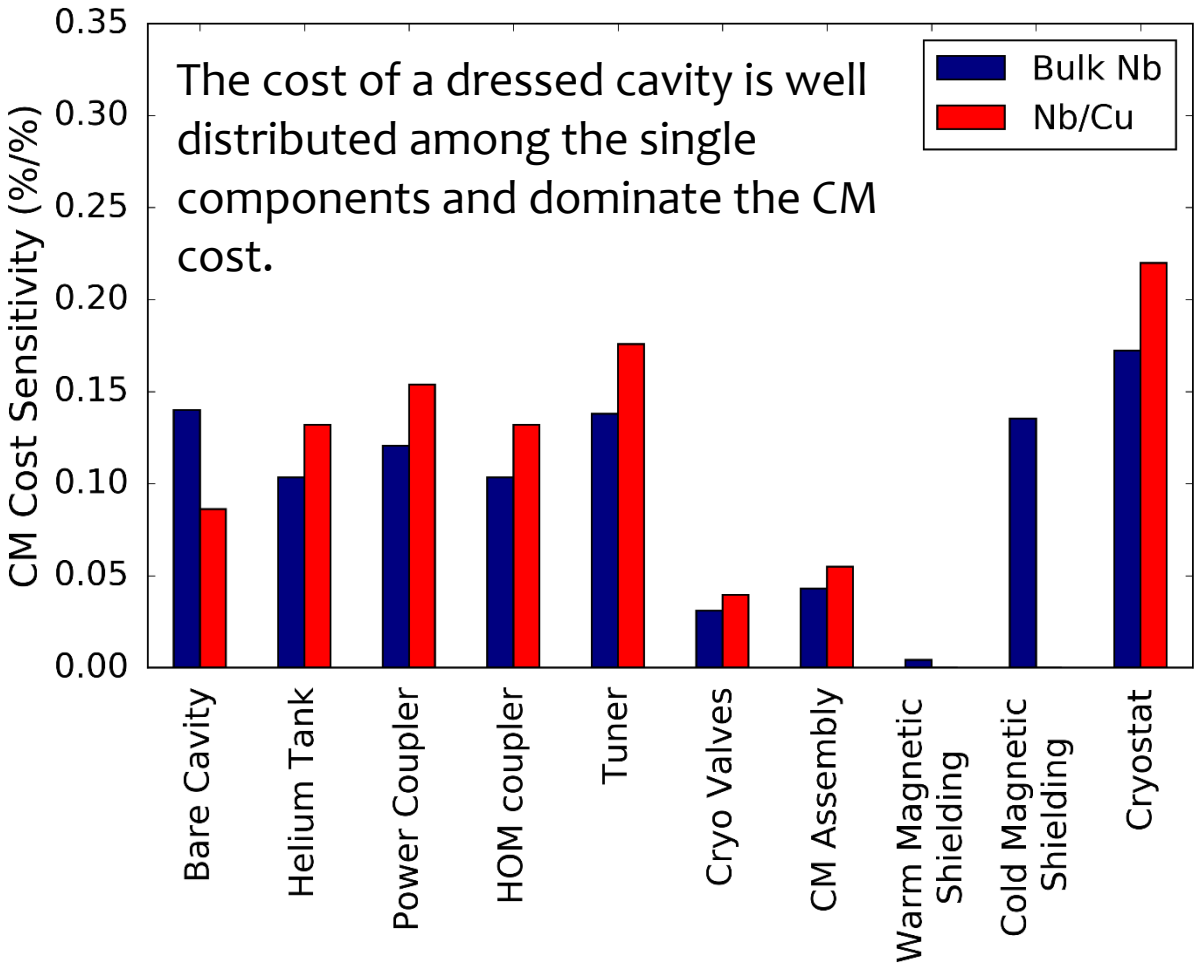
- Cost driver for Nb/Cu cavities:
  - Fabrication
  - Raw material



Production Cost
from Bare Cavity to Cryomodule

	4 Cavities per Cryomodule	
1/cavity	Helium tank	1/cavity
1/cavity	Power Coupler	1/cavity
2/cavity	HOM coupler	2/cavity
1/cavity	tuner	1/cavity
2 per CM	Cryo valves	2 per CM
–	Magnetic shielding	1/meter
1	Cryostat	1
	CM assembly	

Cryomodule
Sensitivity to Production Cost



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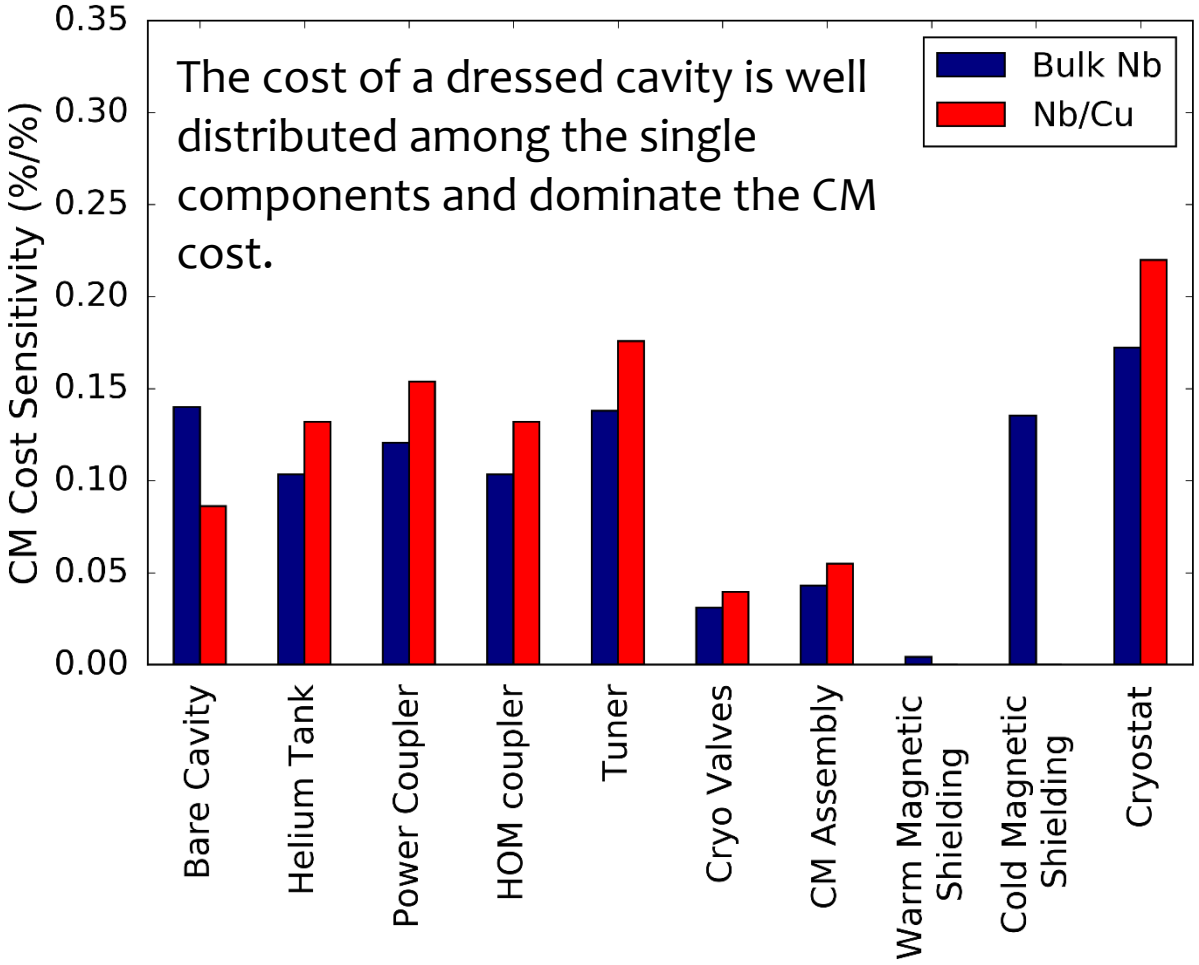
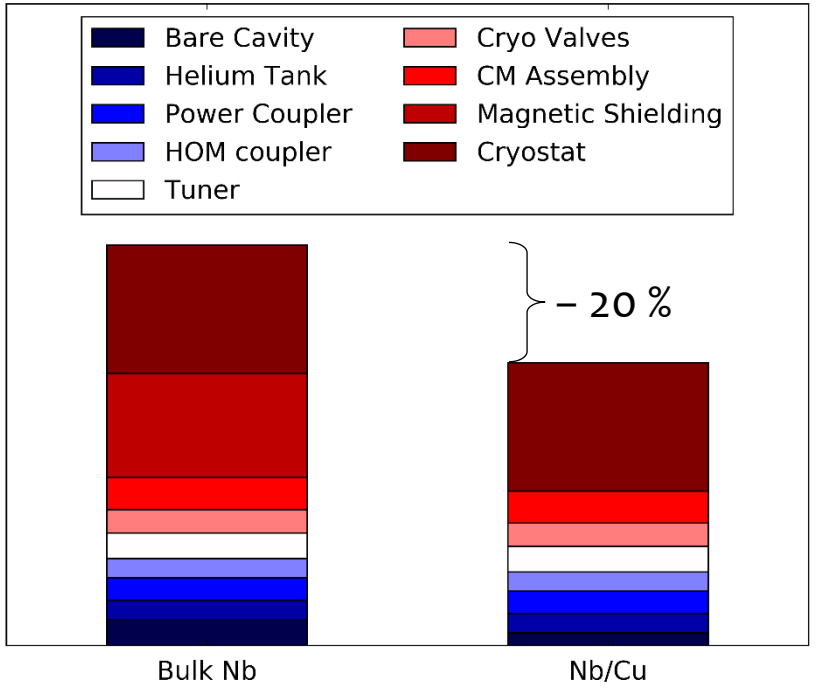
Sensitivity to Production Cost

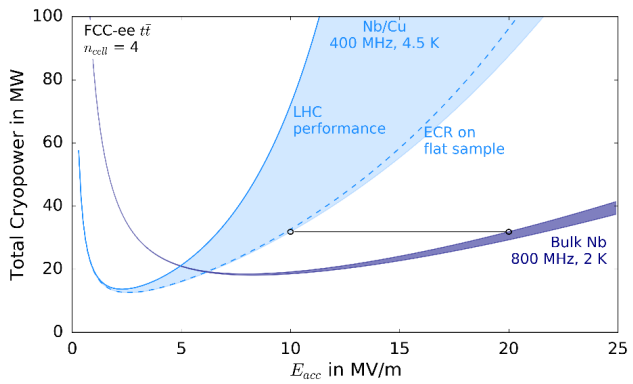




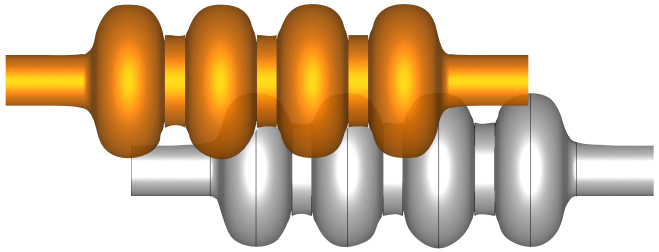
The cost for a CM with 400 MHz Nb/Cu cavities is about 20 % less than for a CM with 800 MHz bulk Nb cavities

Conclusion

- Successful R&D on the energetic condensation techniques will make Nb/Cu at 400 MHz and 4.5 K competitive to bulk Nb at 800 MHz and 2.0 K in terms of cryogenic consumption.
- Significant reduction of the cryogenic consumption requires the development of alternative SRF materials such as Nb3Sn and V3Si.



- Our cost model estimates a reduction of a Nb/Cu cryomodule of 20 % compared to its bulk Nb counterpart.
- Biggest potential for further cost reduction:
  - Fabrication of cavities, helium tanks, power and HOM couplers.



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