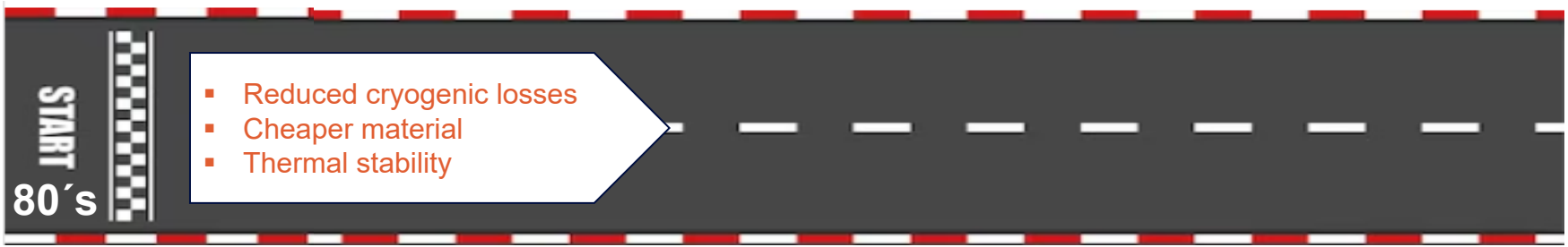
Results of the R&D RF testing campaign of 1.3 GHz Nb/Cu cavities

L. Vega Cid, S. Atieh, A. Bianchi, G. Bellini, L. A. Ferreira, S. Leith, C.P. Carlos, G. Rosaz, W. Venturini Delsolaro

28/06/2023

Motivation

Motivation


START
80´s
Reduced cryogenic losses
Cheaper material
Thermal stability

Motivation

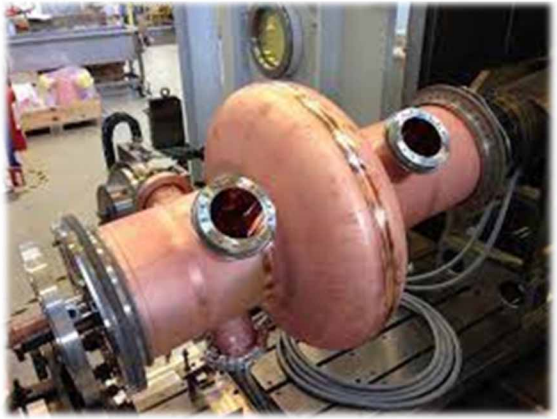
START
80´s

- Reduced cryogenic losses
- Cheaper material
- Thermal stability

- Vast operational experience:
  - LEP
  - HIE-ISOLDE
  - LHC

HIE-ISOLDE

LHC



Motivation

START 80´s

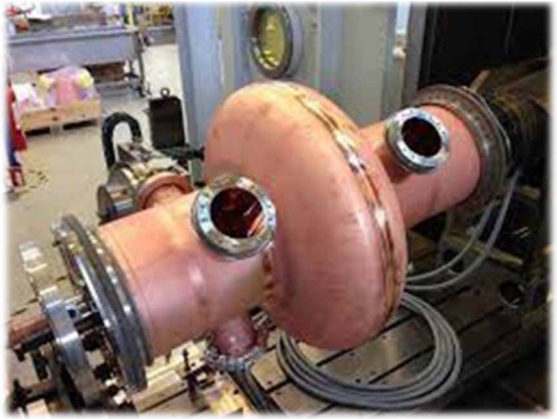
- Reduced cryogenic losses
- Cheaper material
- Thermal stability

- Vast operational experience:
  - LEP
  - HIE-ISOLDE
  - LHC

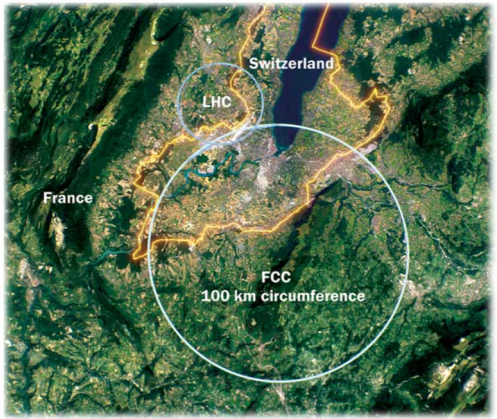
- Future
  - FCC
  - …

HIE-ISOLDE

LHC



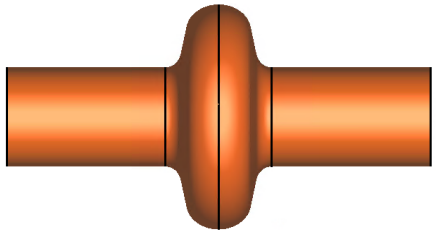
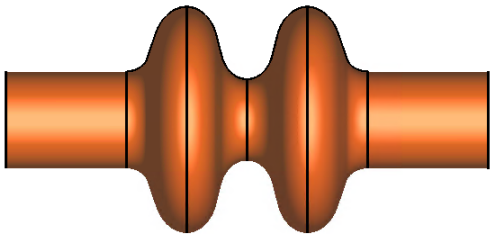
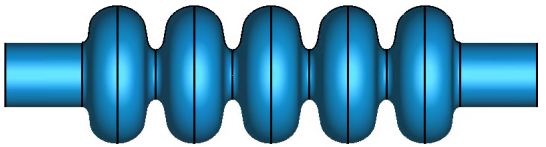
FCC



Motivation

FCC SRF system baseline

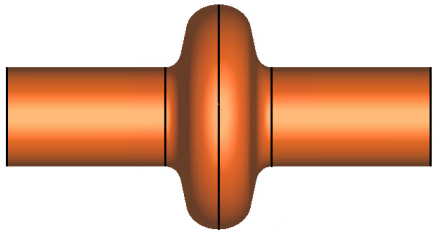
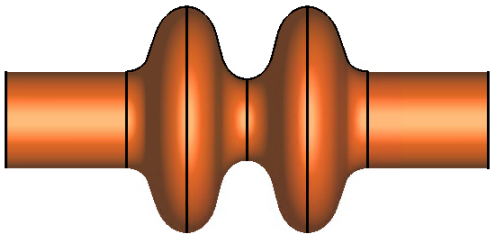
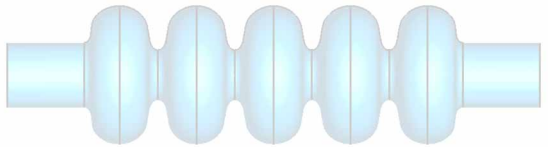
- Number of cavities:1464

Z	W, H	ttbar, booster
		
1-cell Nb/Cu 400 MHz 112 cavities	2-cell Nb/Cu 400 MHz 264 cavities	5-cell bulk Nb 800 MHz 1088 cavities

Motivation

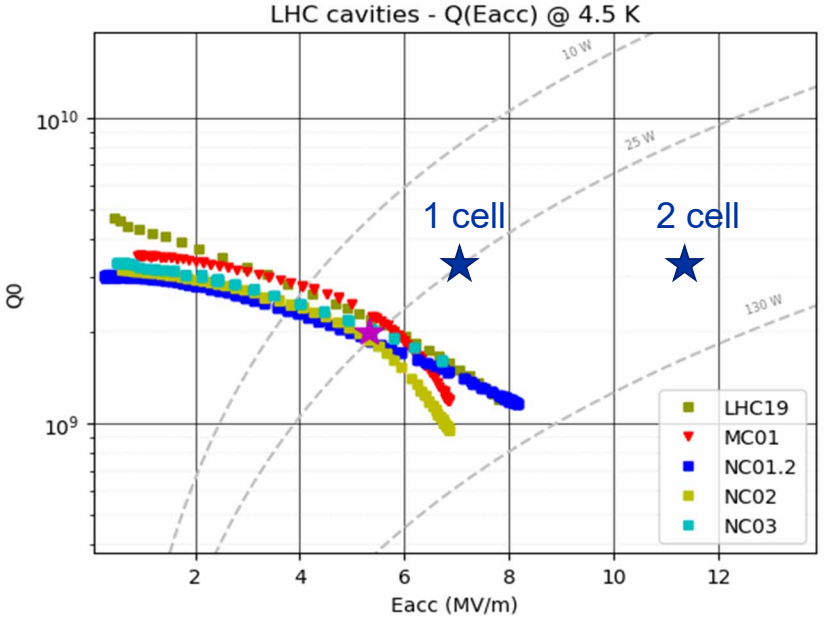
FCC SRF system baseline

- Number of cavities:1464
  - 25% Nb/Cu, 75 Nb

Z	W, H	ttbar, booster
		
1-cell Nb/Cu 400 MHz 112 cavities	2-cell Nb/Cu 400 MHz 264 cavities	5-cell bulk Nb 800 MHz 1088 cavities

Motivation

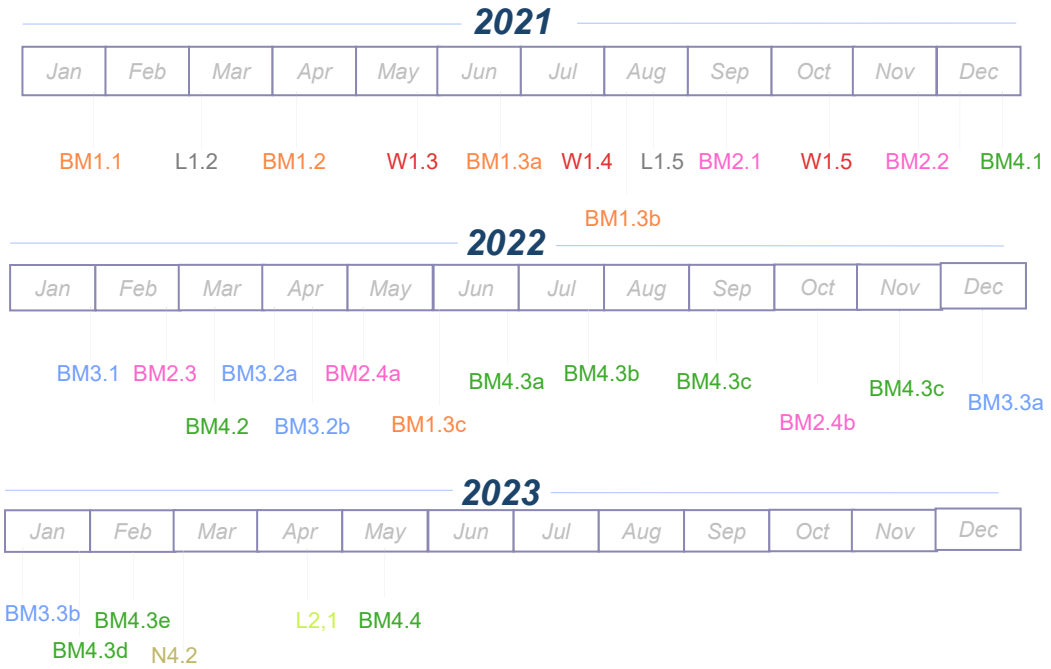
R&D program on 1.3 GHz cavities:
Find a recipe scalable to 400 MHz cavities to meet FCC requirements.



Overview of the R&D program

Overview of the R&D program

31 tests performed since 2021 thanks to the fruitful collaboration!



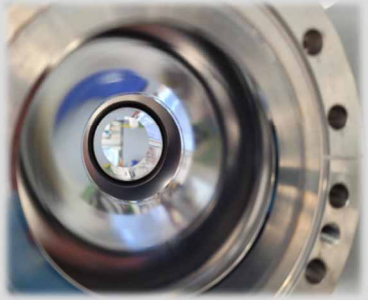
Overview of the R&D program

- *Preparation of the cavities*

Manufacturing high quality substrates

Electropolishing

Niobium deposition



RF testing

Strip coating

Overview of the R&D program

- *Preparation of the cavities*

Manufacturing high quality substrates

Electropolishing

Niobium deposition

RF testing

Strip coating

Overview of the R&D program

➢ *Preparation of the cavities*

Substrate manufacturing

✓ *Total: 7*

4x Monoblock (BM)

Courtesy: K. Scibor

2x Electroformed (L)

1x Internal weld (W)

	Ra [µm]
External	7-10
Internal	0.6-1

See J. Święszek, “Engineering developments towards seamless substrates” , presented at FCC Week 2023.

Overview of the R&D program

➢ *Preparation of the cavities*

Substrate manufacturing

✓ *Total: 7*

4x Monoblock (BM)

Courtesy: K. Scibor

2x Electroformed (L)

1x Internal weld (W)

	Ra [µm]
External	7-10
Internal	0.6-1

See L. Lain, “Electrodeposition of copper applied to the manufacture of seamless superconducting rf cavities”, Phys. Rev. Accel. Beams 24, 082002, 2021.

Overview of the R&D program

➢ *Preparation of the cavities*

Substrate manufacturing

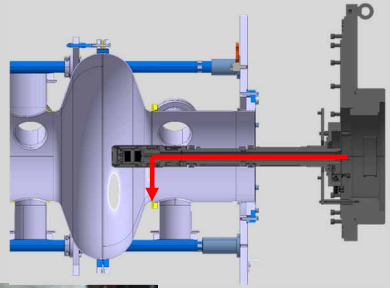
✓ *Total: 7*

4x Monoblock (BM)

Courtesy: K. Scibor

2x Electroformed (L)

1x Internal weld (W)



	Ra [µm]
External	7-10
Internal	0.6-1

See T. Demaziere, “Engineering developments towards seamless substrates” , presented at FCC Week 2023.

Overview of the R&D program

➢ *Preparation of the cavities*

Manufacturing high quality substrates

Electropolishing

Niobium deposition

Strip coating

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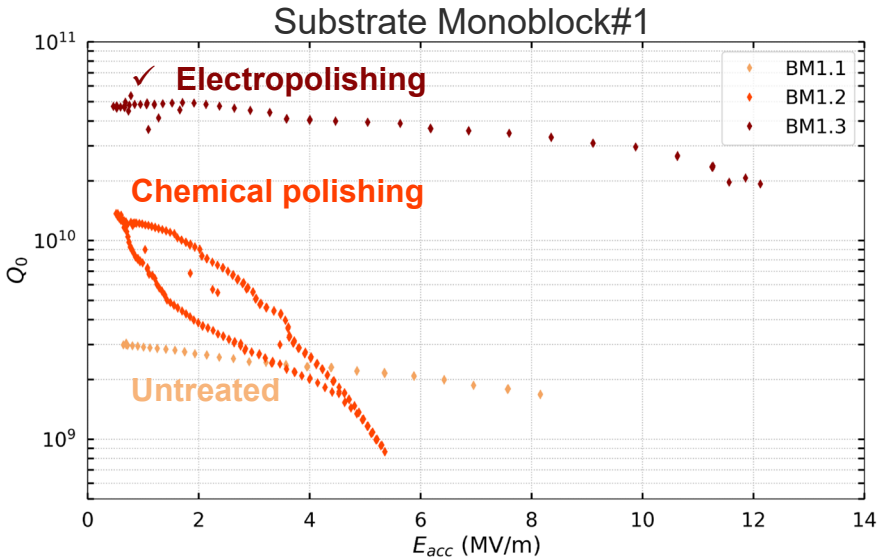
Overview of the R&D program

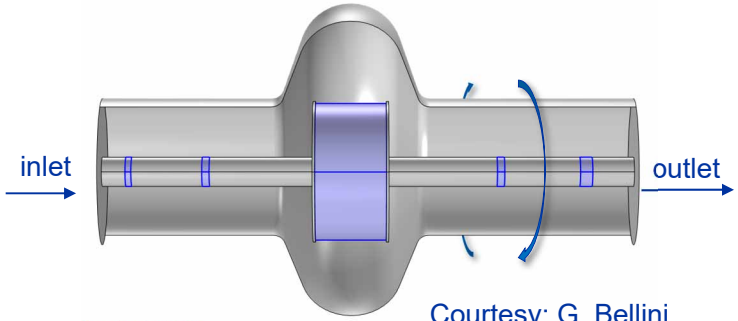
➢ *Preparation of the cavities*

Electropolishing



1,3 GHz
Fluid dynamics and cathode design optimized

400 MHz
Ready to transfer know-how



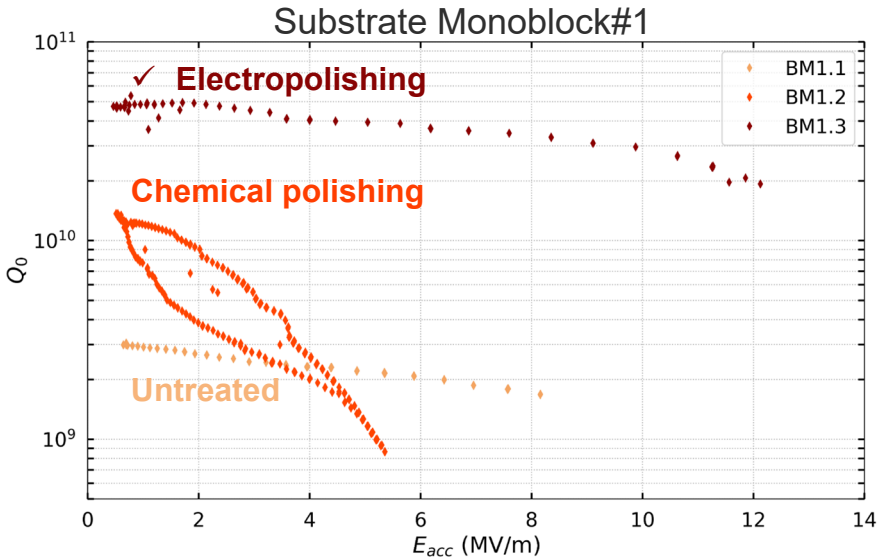
Courtesy: G. Bellini

See G. Bellini, "Electropolishing 1300 & 400 MHz SRF copper ", presented at FCC Week 2022.

Overview of the R&D program

➢ *Preparation of the cavities*

Electropolishing



1,3 GHz
Fluid dynamics and cathode design optimized

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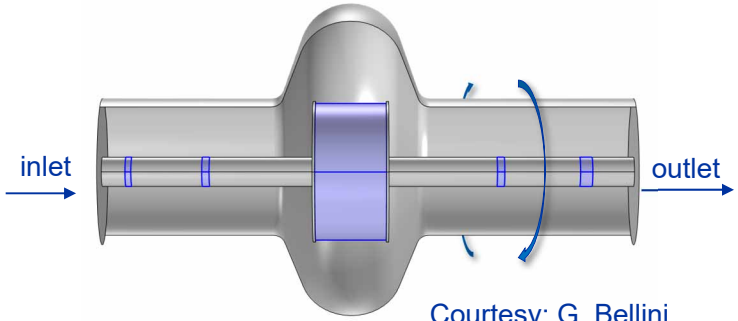

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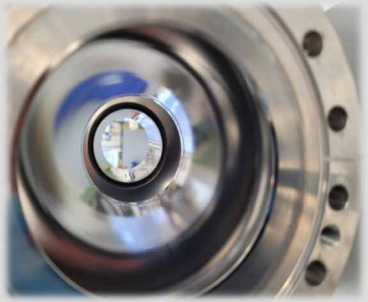
Overview of the R&D program

- *Preparation of the cavities*

Manufacturing high quality substrates

Electropolishing

Niobium deposition



Strip coating

RF testing

Overview of the R&D program

➢ *Preparation of the cavities*

Niobium deposition

Various techniques tested on QPR samples

*See M. Arzeo et al, "*Enhanced radio-frequency performance of niobium films on copper substrates deposited by high power impulse magnetron sputtering*",* Supercond. Sci. Technol. 35 054008

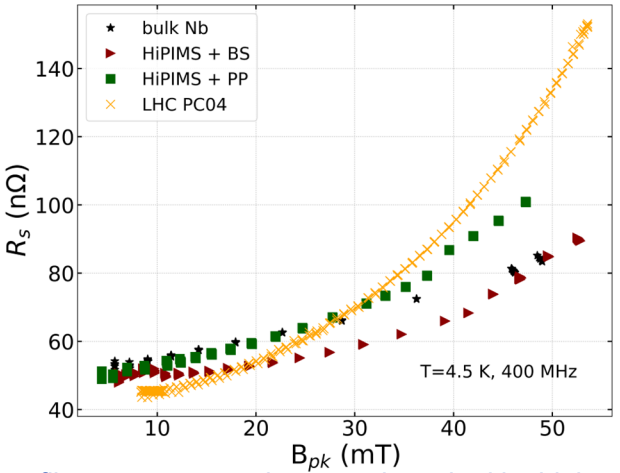
Overview of the R&D program

➢ *Preparation of the cavities*

Niobium deposition

Various techniques tested on QPR samples

HIPIMS gave best results



DC magnetron sputtering

HiPIMS Positive Pulse

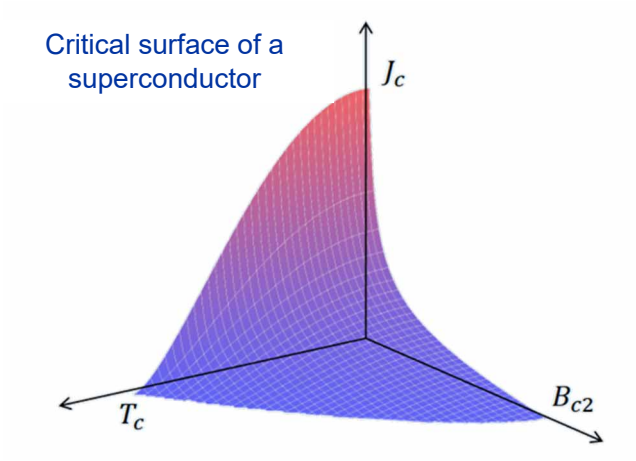
✓ **HiPIMS**
Bulk Nb

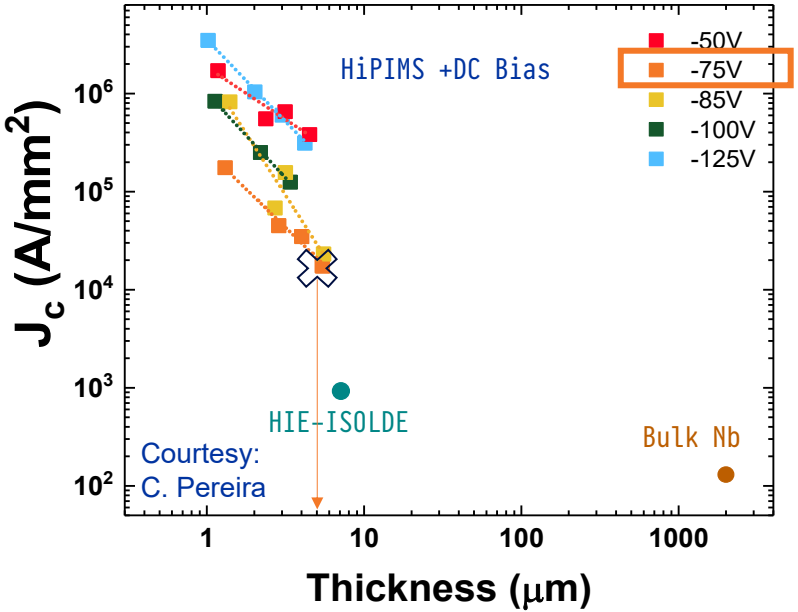
*See M. Arzeo et al, "*Enhanced radio-frequency performance of niobium films on copper substrates deposited by high power impulse magnetron sputtering*",* Supercond. Sci. Technol. 35 054008

Overview of the R&D program

➢ *Preparation of the cavities*

Niobium deposition



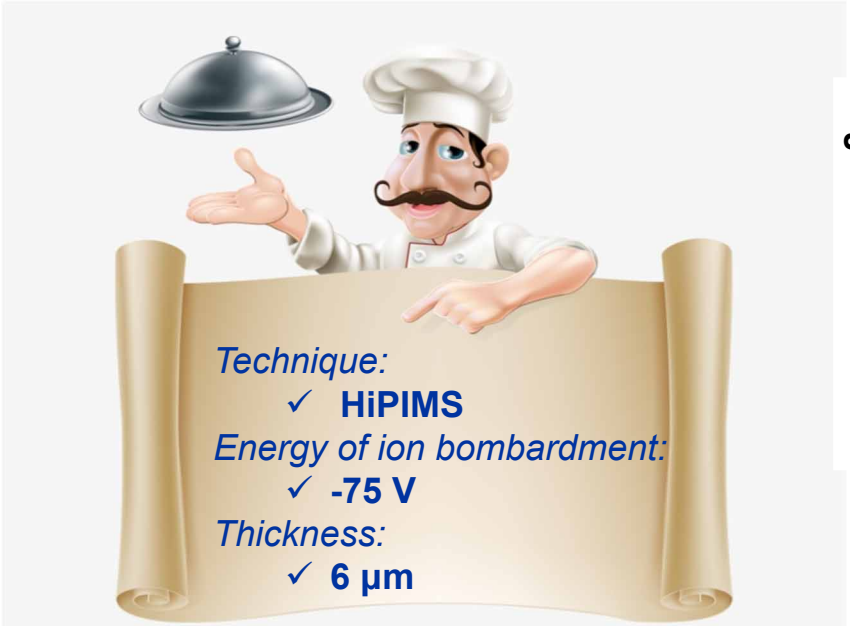


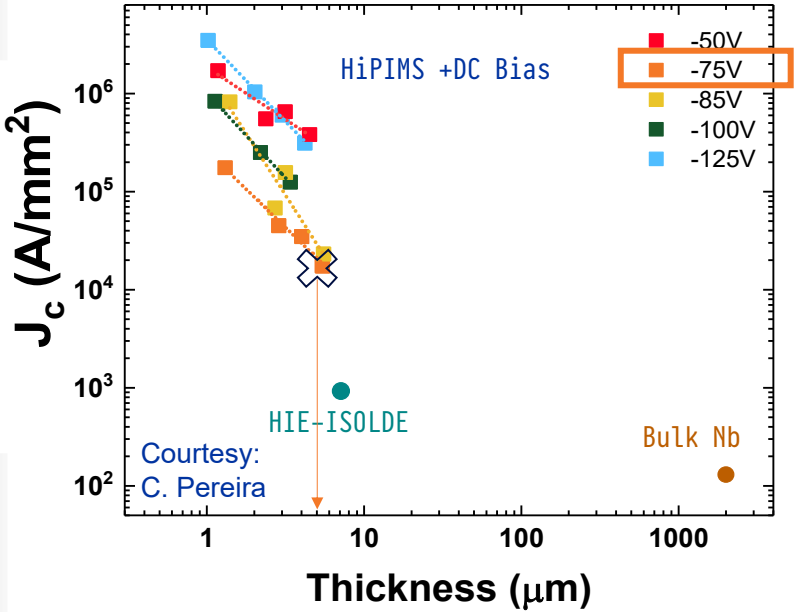
See C. Pereira, "HIPIMS Nb coatings, from 1.3 GHz to 400 MHz" presented at FCC Week 2023.

Overview of the R&D program

➢ *Preparation of the cavities*

Niobium deposition





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Overview of the R&D program

- *Preparation of the cavities*

Manufacturing high quality substrates

Electropolishing

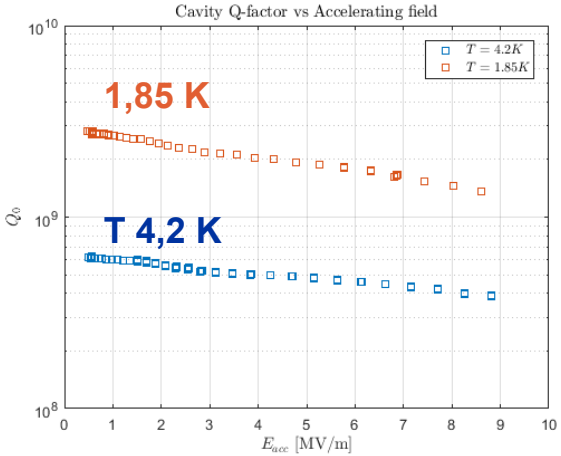
Niobium deposition

Strip coating

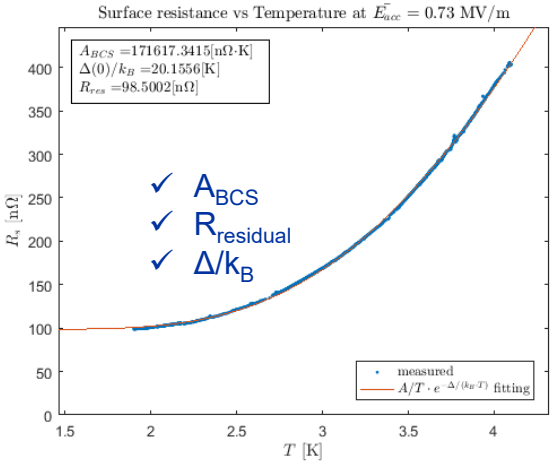
RF testing

RF testing protocol

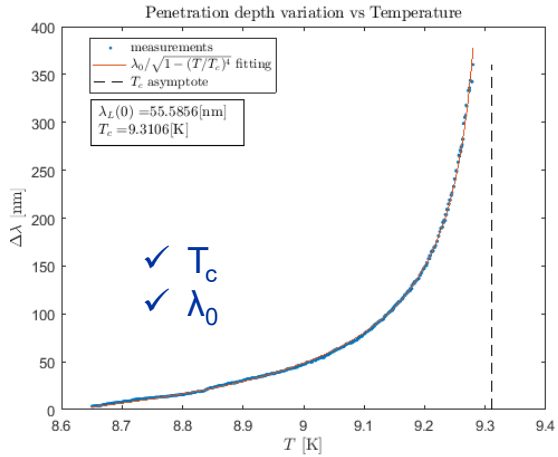
❑Q vs E_{acc}



❑Q vs Temperature



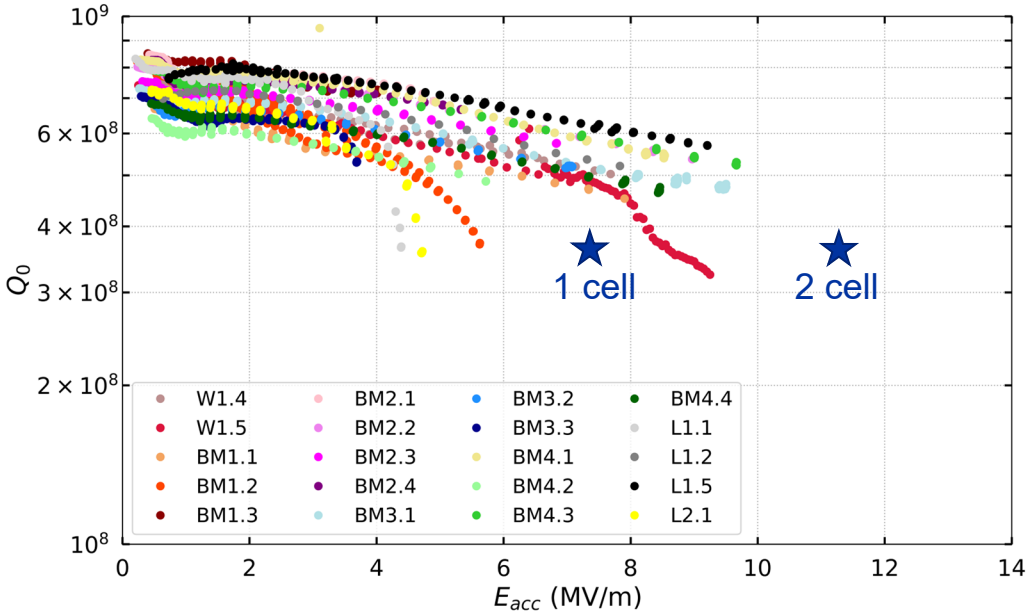
❑Frequency vs Temperature



RF Results

RF Results

- *Reproducibility at 4,2 K*

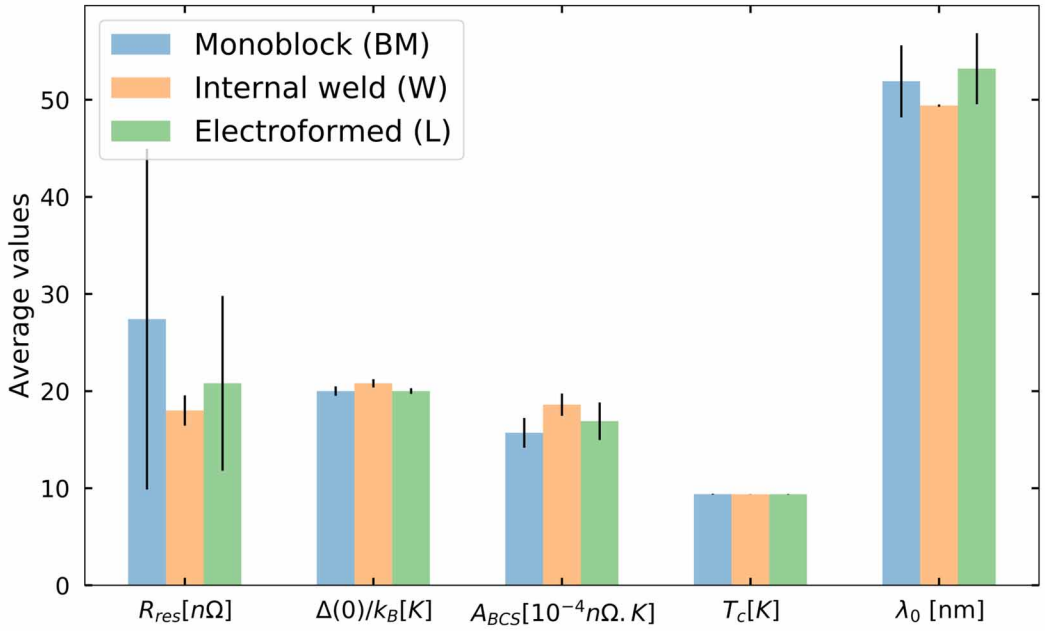


1. High repeatability at 4.2 K, with “FCC SRF requirements” met.

Eacc limited due to restrictions at cryolab: No radiation allowed.

RF Results

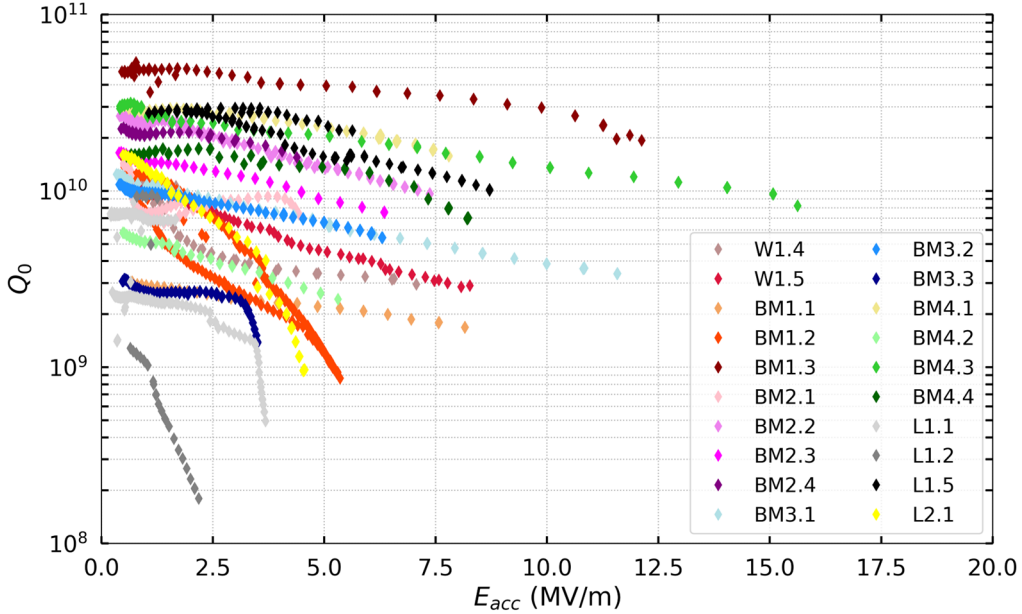
➢ *Reproducibility of superconducting parameters*



1. High repeatability at 4.2 K, with “FCC SRF requirements” met.
2. Averaged superconducting parameters are very similar regardless the manufacturing technique.
3. Low variability: Coating process under control.
4. Residual resistance spoiled due to defects, obvious at 1.85 K.

RF Results

➢ *Reproducibility at 1,85 K*



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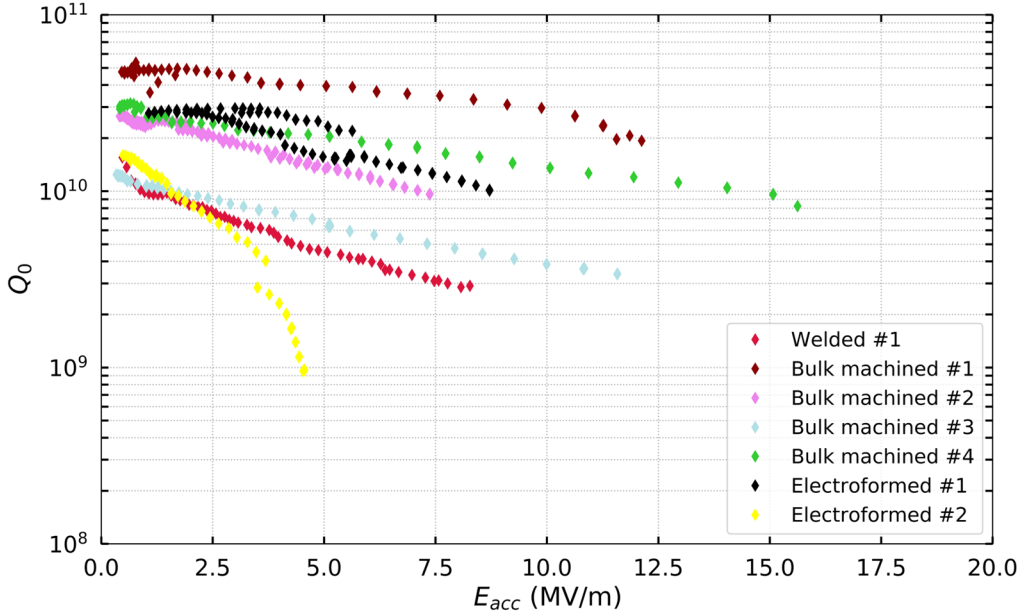
5. High variability at 1.85 K.

Eacc limited due to restrictions at the Cryogenics laboratory: No radiation allowed.

RF Results

➢ *Reproducibility at 1,85 K*



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4. Residual resistance spoiled due to defects, obvious at 1.85 K.
5. High variability at 1.85 K.
6. Not related to manufacturing technique.

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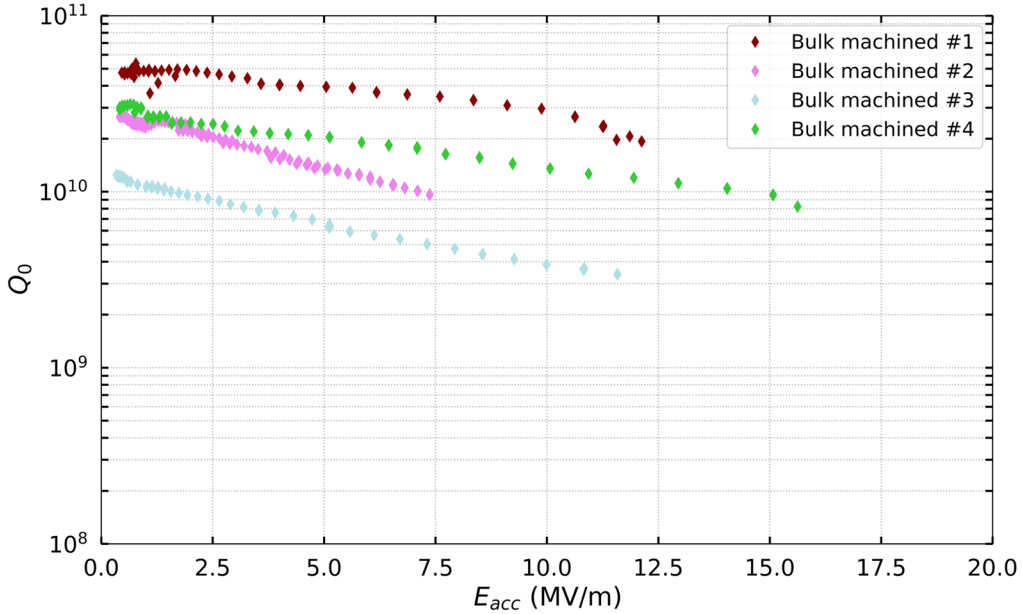
RF Results

➢ *Reproducibility at 1,85 K*



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2. Averaged superconducting parameters are very similar regardless the manufacturing technique.
3. Low variability: Coating process under control.
4. Residual resistance spoiled due to defects, obvious at 1.85 K.
5. High variability at 1.85 K.
6. Not related to manufacturing technique.
7. Influenced by copper characteristics.

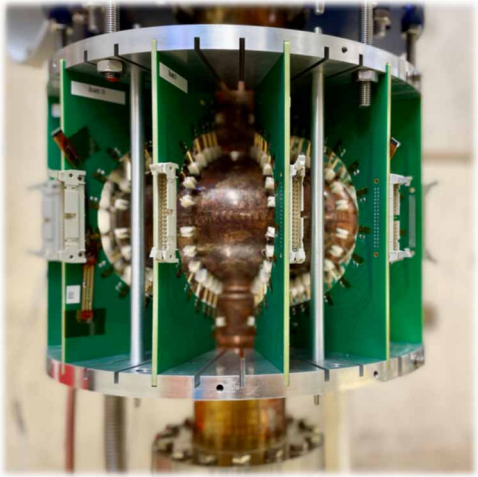
Current research lines

Current research lines

- *Improvement of cooling*

Studies performed with thermal mapping system

- Not uniform heat distribution.
- Observed cold areas suggest improved cooling due to bubble formation.



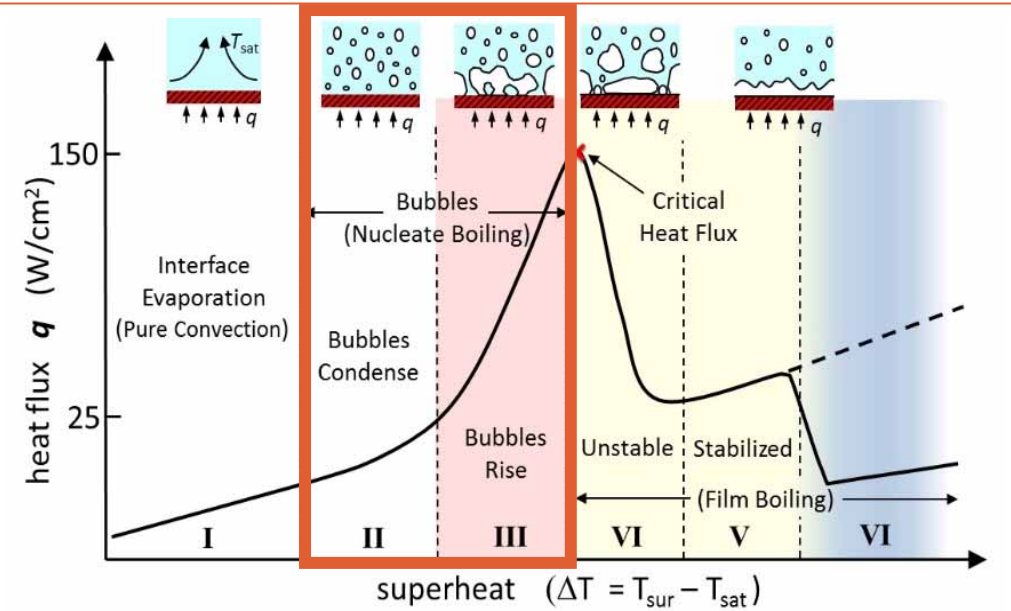
Courtesy:
A. Bianchi

*See A. Bianchi et al, "*Temperature Mapping on a Niobium-Coated Copper Superconducting Radio-Frequency Cavity", arXiv:2305.09597 [physics.acc-ph], 2023.

Current research lines

- *Improvement of cooling*

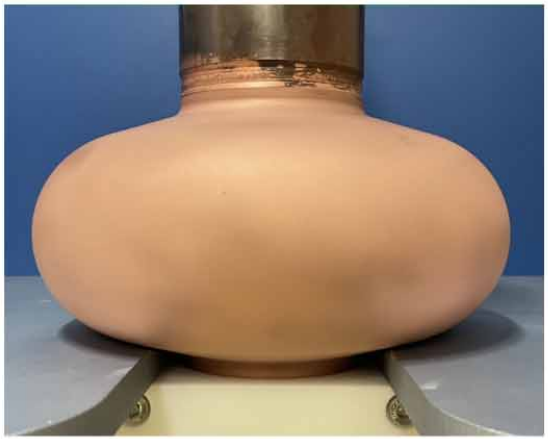
Nucleation sites for bubble formation → Roughness



Current research lines

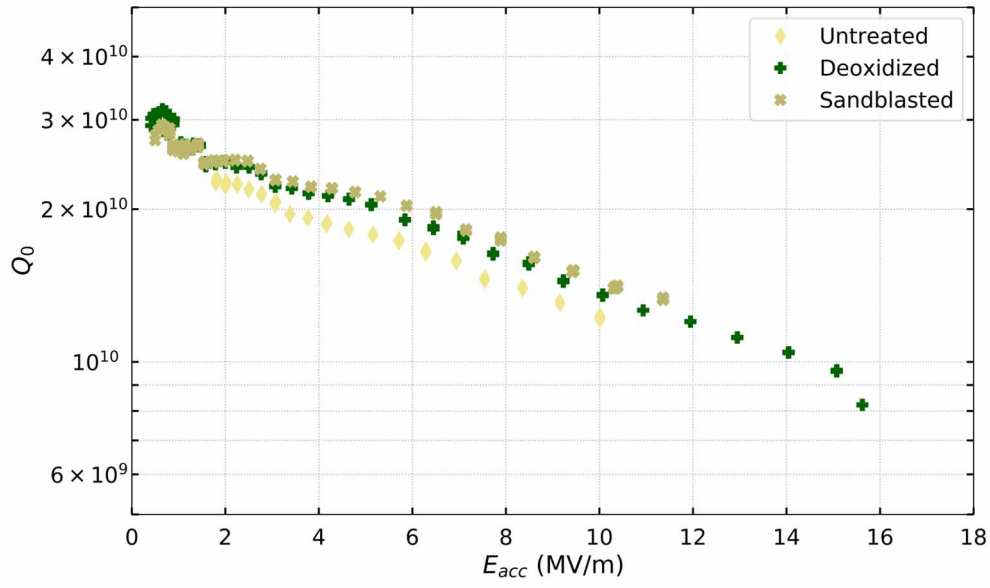
- *Improvement of cooling*

Initial state → Deoxidation +HPWR → Sandblasting +HPWR



Current research lines

- *Improvement of cooling*



Sandblasted

- Not enough improvement to justify systematic application.

Deoxidized

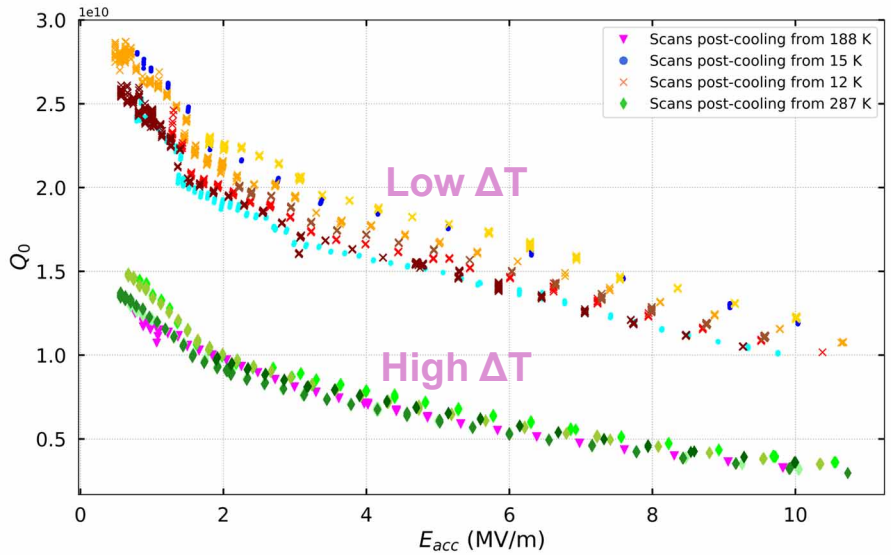
- Reaching highest E_{acc} might be due to extended HPWR: To be systematically applied.

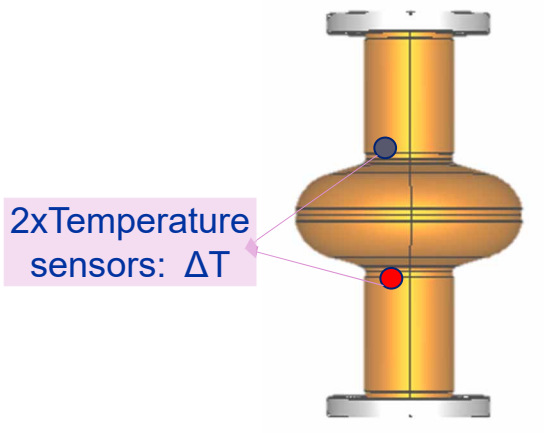
Current research lines

➢ *Mitigate thermoelectric currents*

RF performance improved when ΔT is minimized at NC/SC transition

Thermoelectric currents



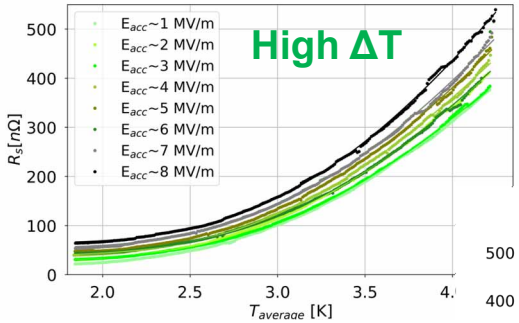


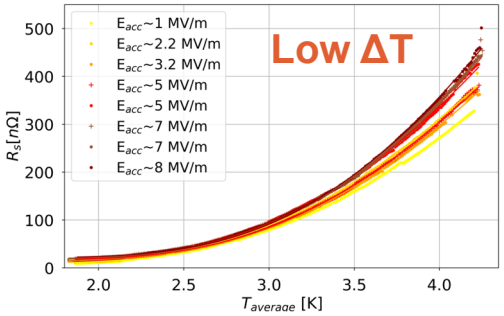
Current research lines

➢ *Mitigate thermoelectric currents*

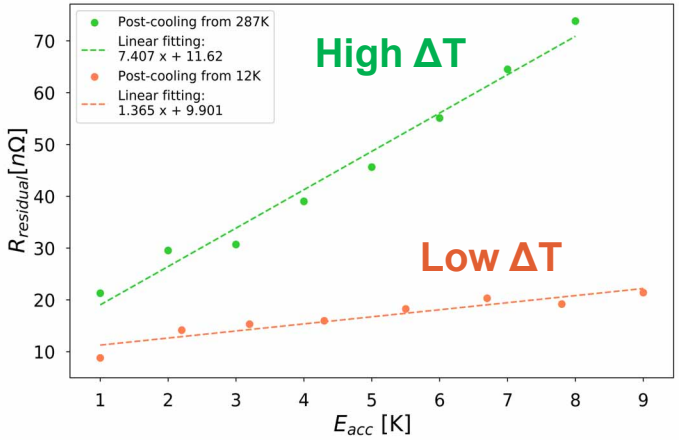
RF performance improved when ΔT is minimized at NC/SC transition

Thermoelectric currents





Q slope is partially caused by this effect!



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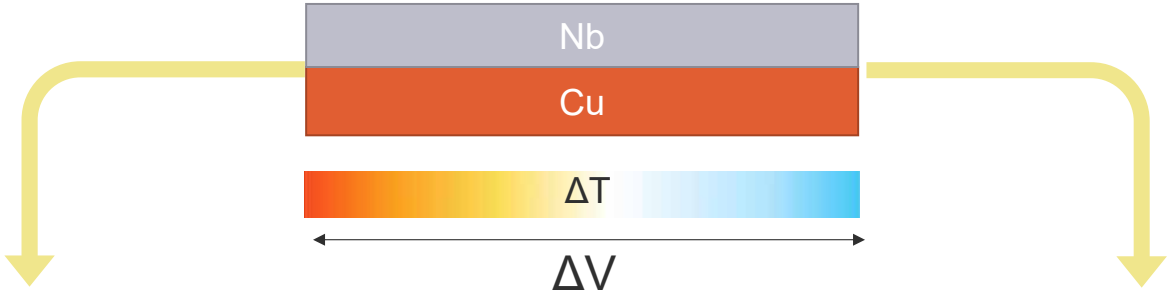
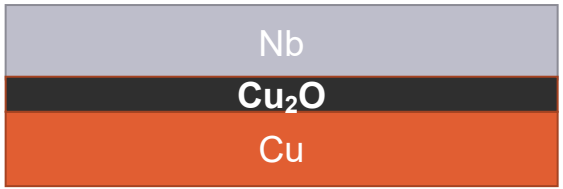
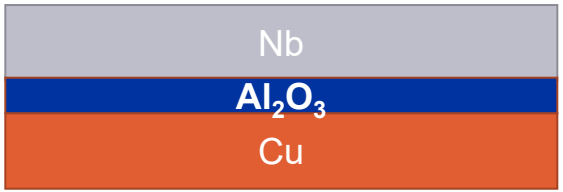


➢ Grow oxide layer before coating

✓ A cavity to be produced soon.



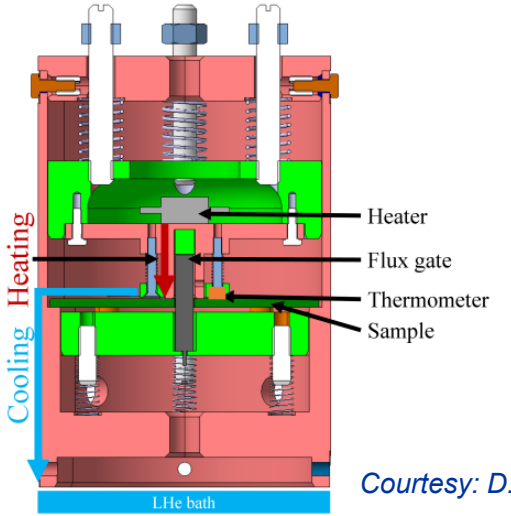
➢ Deposit Al_2O_3 /Y_2O_3 by ALD (CEA):



Current research lines

- *Mitigate thermoelectric currents*

Studies ongoing on flux expulsion lenses *(see MOPMB003)*



Courtesy: D. Turner

*D. Turner et al, "*Flux Expulsion Lens: Concept and Measurements", poster presented at SRF23 (MOPMB003).

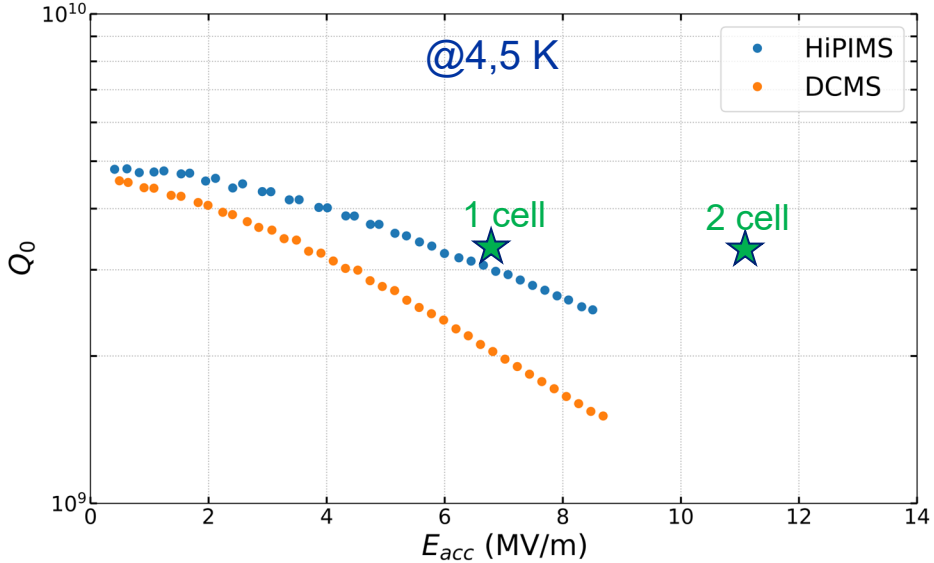
Next steps towards FCC

Next steps towards FCC

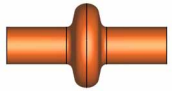
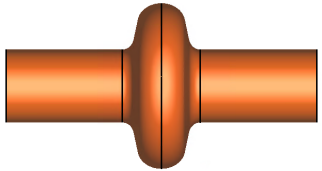
➢ *HiPIMS tested in 400 MHz LHC type cavity*

x Not optimized substrate:
- External welds at equator.
- SUBU instead of EP.

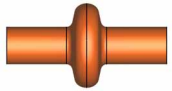
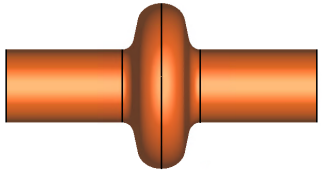
Very promising results!

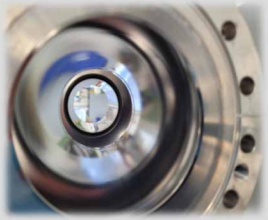


Summary

	Manufacturing high quality substrates	*Electropolishing*	*Niobium deposition*
1,3 GHz 			
400 MHz 			

Summary

	Manufacturing high quality substrates	*Electropolishing*	*Niobium deposition*
1,3 GHz 	✓ Monoblock ✓ Internal weld ✓ Electroformed ➢ Hydroformed (KEK)	✓ Optimized.	✓ Optimized.
400 MHz 	➢ Monoblock ➢ Hydroformed (KEK) ➢ Internal weld	➢ Ready to be applied.	✓ Tested at 400 MHz LHC type cavity. ➢ To be repeated in optimal conditions.



Thanks for your attention!

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