CAVITY SUBSTRATE DEVELOPMENT

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On behalf of CERN EN-MME Group & FCC SRF Res.&Dev. Work Packages

FCC SRF Fab WP: Towards Cavity (Substrate) Manufacturing

End goal is to **provide cavities conform to FCC baseline** requirements. In order to do this:

- **Supporting R&D** of all stakeholders involved
- **Identify the best manufacturing strategy** in view of *SRF performance*, *series production*

Provide substrates for RF & coating studies	Surface quality, Reliability
Validate best manufacturing processes for series	Benchmark fabrication processes (especially if uninfluenced by the size of the cavity) : …internal EB welding, machining of RF surfaces, spinning, necking, deep drawing… Fabrication cost reduction studies & Industrialization of sub-elements…

Activities involve: 1.3 GHz, 800 MHz, 400 MHz (LHC & FCC Design)

Cut-Offs : industrialization study of 400 MHz design → Done

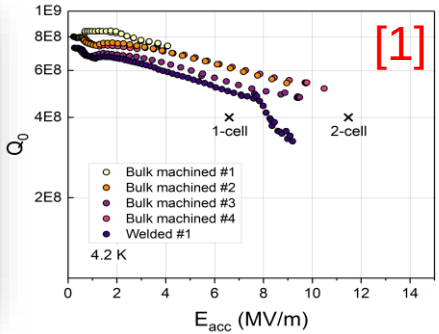
Machining from Bulk

Roughness Ra after machining		Max Geom. Deviations	
Beam tube (Iris)	Equator	RF Shape	Wall thickness
0.15÷0.25 µm		~ 20 µm	< 20 µm

Monoblock cavities :

- **Optimal surface and shape conformity** — *Provide substrates for RF & coating studies*
- Best & Reproducible for Nb coating R&D
- Damaged Layer : L_1 ~0.5 µm / L_2 ~4 µm — *Minimization of surface removal processes*

1.3 GHz Ellipt. Monoblock



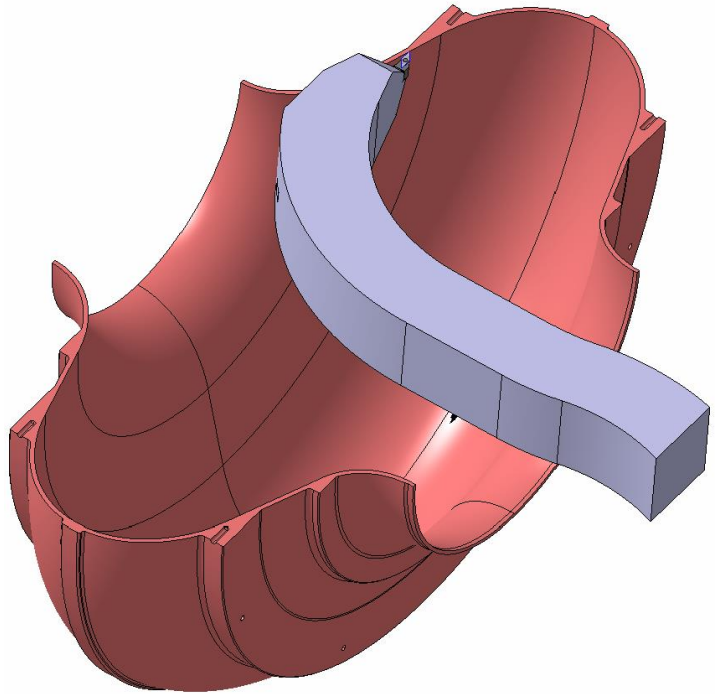
- **Reduce qty subcomponents & multi-technology**
- .. some major fab costs, welds, surface treatments, pretuning, …

- Now **established** fabrication strategy @ CERN.
- Currently produced also for Collabs (JLAB, STFC)

Machining from Bulk

400 MHz LHC Ellipt. Monoblock

- Confirm **scalability** of optimized **Nb-coating** process
- Comparable with available data
- **Status**: to be welded next week ⟶ Nb coating …

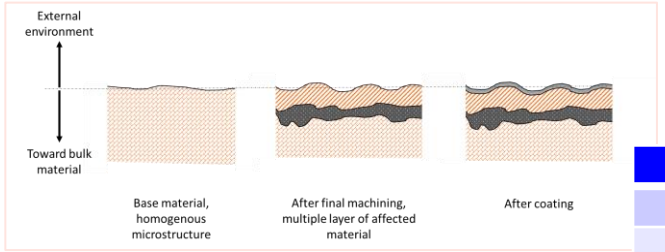


400 MHz FCC Ellipt. Monoblock

- Development of product for HTCryomodule
- Validate FCC design
- Safety net for series

R&D and Process Characterisation : Machining

Study & define machining parameters (lubricant, tool, cutting parameters,..)
Aim: master & minimise the **impact of machining on the surface layer** (thus influence on coating performance

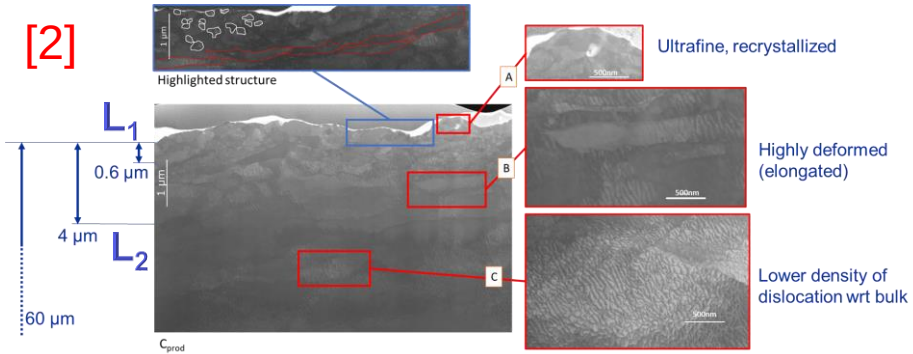


Cu OFE

Turning

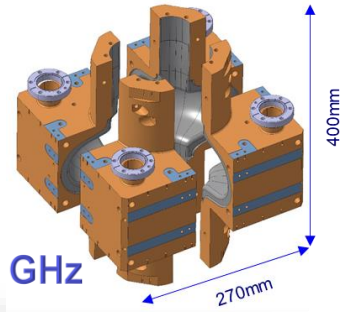
Damaged Layer	
L1	L2
0.5 µm	4 µm

[2]



Cu OFE

Milling



FCC SWELL 1.3 GHz

[3,4]

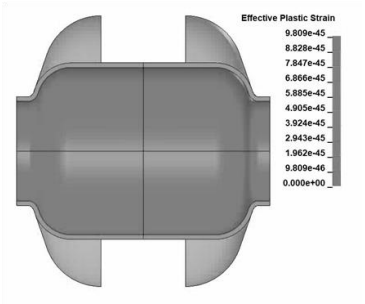
Roughness Ra	
Beam tube (Iris)	Equator
0.2 µm	0.2 µm

Damaged Layer	
L1	L2
0.5 µm	Few µm

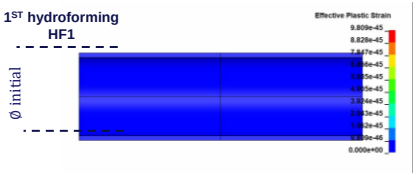
Shaping Processes

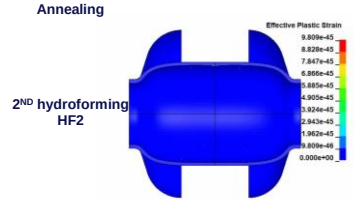
Multi-step Hydroforming
1.3 GHZ KEK –CERN

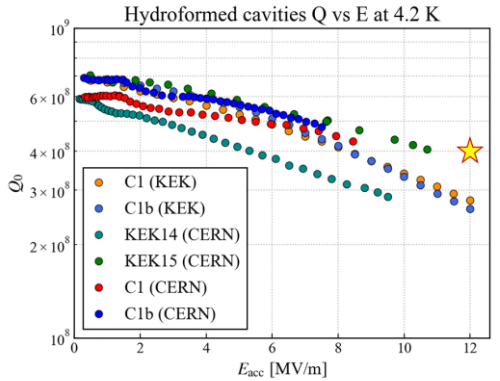
Necking + Hydroforming



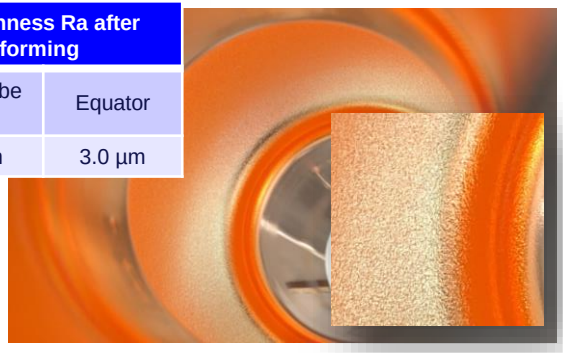
Reviving technology of the past millennium (DESY, CERN, KEK) … [5,6,7]
Augmented: process design, testing, process control
Status: **successful forming.** Further cold testing + R&D for amelioration surface treatments

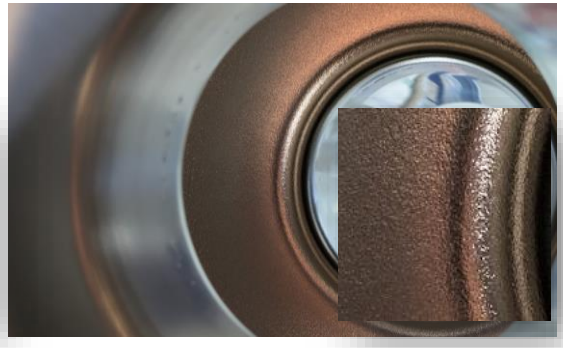






Roughness Ra after forming	
Beam tube (Iris)	Equator
1.0 µm	3.0 µm

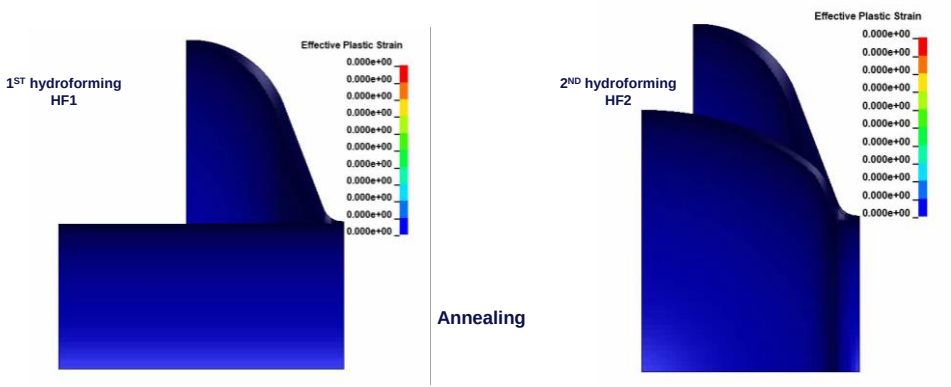


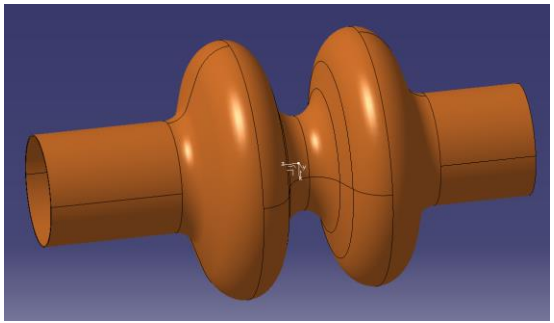


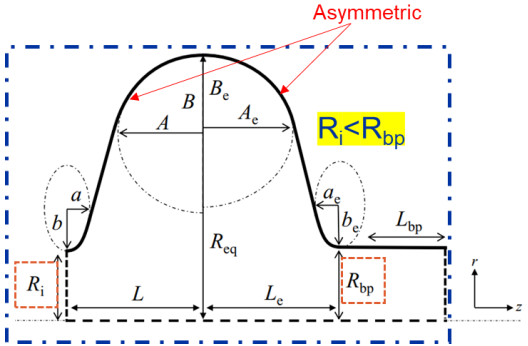
Currently shelved:

- [+] reduced strains @ shaping
- [-] Added Multi-technology
- [-] Poor surface results in compression
- [-] Material availability for lower frequencies

Hydroforming : 400 MHz Strategy

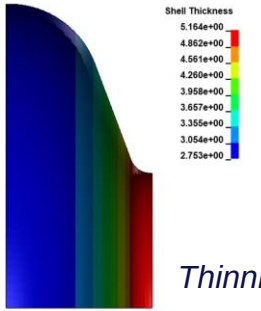






LHC Design:

- Successful within the FE realm
- → CERN in-house trials



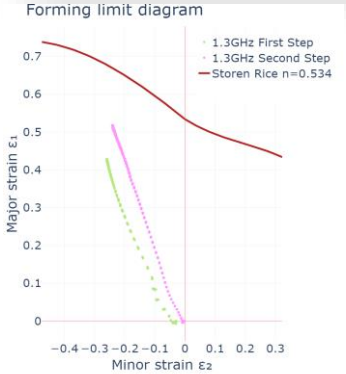
Thinning ~ 50%

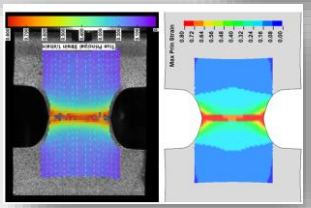
Current FCC Design:

- Challenging asymmetry and ratios
- Study ongoing with industry (DE)

R&D and Process Characterisation : Hydroforming

[8]





Material characterization:

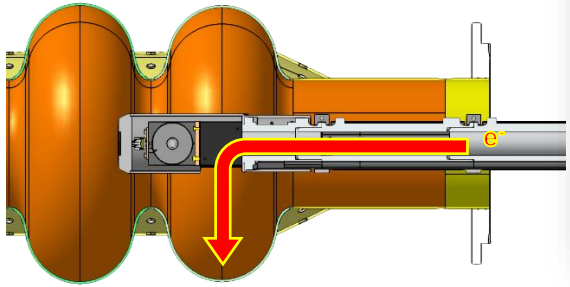
- *Structural behavior*
- Failure model
- Targeted response strain vs. thermal annealing

Process characterization

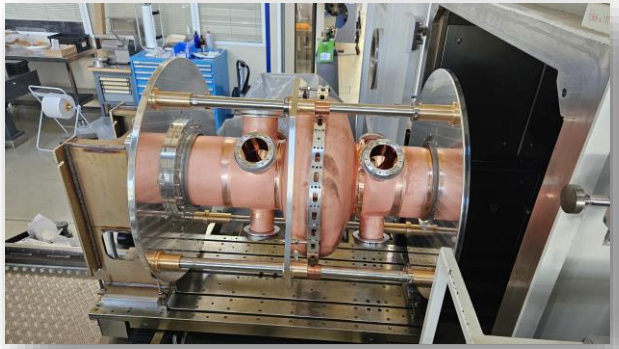
@ different steps of fab (raw→full cavity)

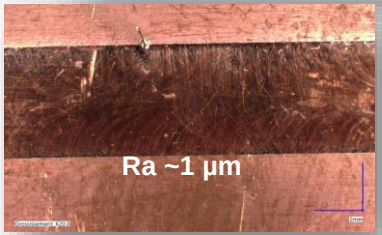
- *Surface properties* (roughness, orange peel)
- *Hydrogen content*

EB Welding



Schema on 800 MHz multi-cell cavity





Final welding on SRF cavities is a **challenging step**:

- RF-compatible full penetration welds are difficult to obtain
- Complex access to perform cosmetic pass

Solution: **EB deflector** to bend the electron beam 90° from the source
Interest: gives access to RF side (internal surface) for cosmetic pass

Status:

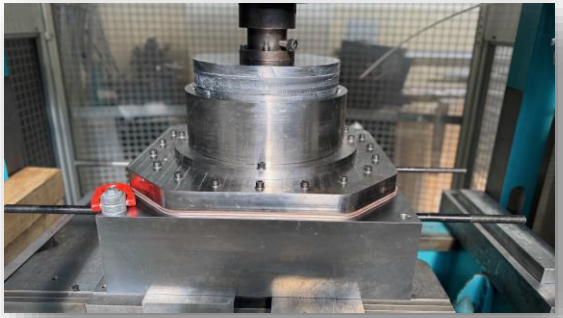
- 400 MHz : 1x+1x (LHC geo) cavities successfully welded, coated and ready for RF test
- Other frequencies : 800MHz, 1.3 GHz, both Cu OFE & Nb

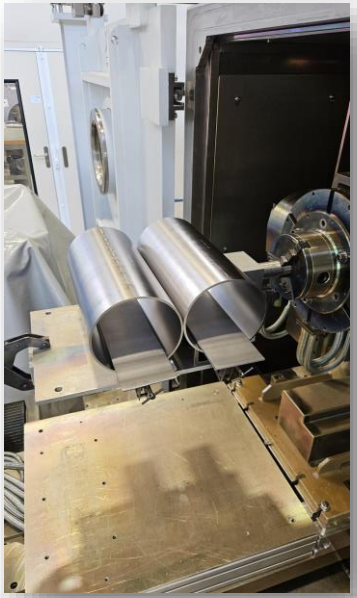
Next:

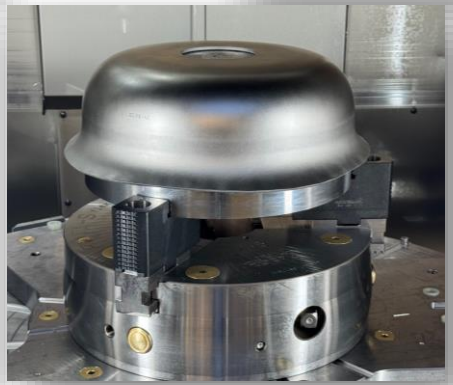
- Development of local repair strategy using deflector (lack of fusion, undercuts & repair of holes)

800 MHz

- Production of 10x Bulk Nb Prototypes
- Collab. FNAL, IJCLab, CORNELL, CERN
- Status : first two half-cells @ calibration



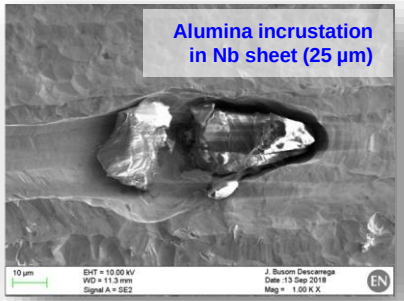




R&D and Process Characterisation : Bulk Nb Production

Stemming from different CERN projects
Established strategy on:

- pollution of Niobium surface by different materials employed in manufacturing
- ability to remove such pollution



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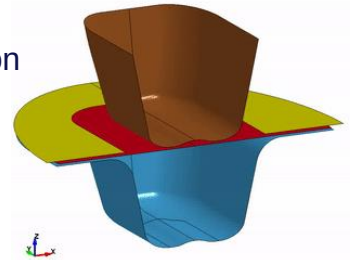
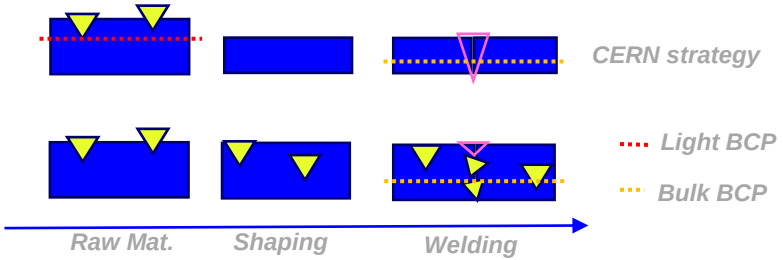
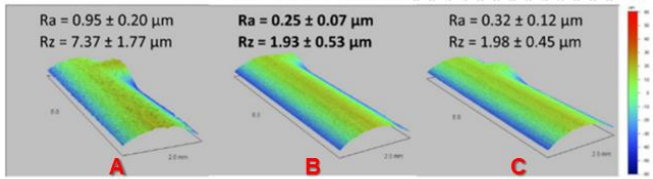
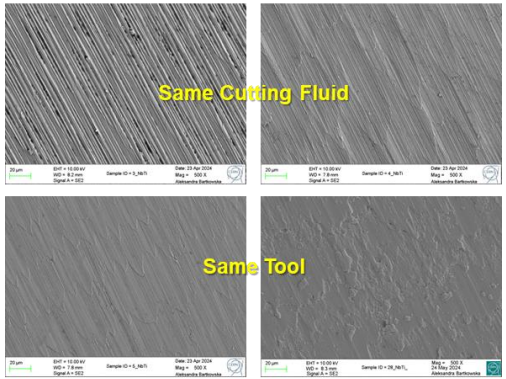


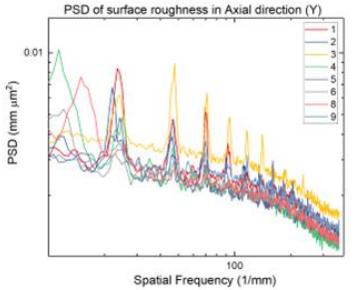


Niobium Hook Milling [10]
Same : milling strategy & tools
Different : cutting fluids (A, B, C)



Nb47Ti Milling
Same: milling strategy & tool family





Thank you for your attention!

References:

[1]	Courtesy of F. Peauger, G. Rosaz [CERN]
[2]	"Experimental analysis of subsurface integrity during fine turning of OFE copper for radiofrequency cavity manufacturing" / A. Camellin et al. // https://www.sciencedirect.com/science/article/pii/S092401362100443X
[3]	"SWELL and Other SRF Split Cavity Development" / F. Peauger et. al. // https://cds.cern.ch/record/2844840
[4]	"Impact of machining strategy on OFE copper for SRF applications" / F. Belkhir et al. / https://mrforum.com/product/9781644903131-215/
[5]	"Novel Approaches in Characterization and Modelling of Fabrication Processes for SRF Components" / J.S. Swieszek et al. // https://doi.org/10.18429/JACoW-SRF2023-TUPTB038
[6]	Q0_E plot courtesy of H. Araki [KEK], K. Brunner [CERN]
[7]	"Full seamless copper substrate accelerator cavity manufactured by tube hydroforming" / M. Yamanaka et al. / International Journal of Advanced Manufacturing Technology // https://doi.org/10.1007/s00170-025-15686-6
[8]	"Forming Limit Diagram of Annealed Copper OFE Thick Sheets: A Novel Approach for the Manufacturing Design of Superconducting RF Cavities" / A. Gallifa et al. // https://dx.doi.org/10.2139/ssrn.4756181
[9]	"Technical progress of crab cavity in fabrication and tests at CERN" / M. Garlaschè // TTC Meeting 2018
[10]	"State Of The Art Of Niobium Machining For SRF Applications" / P. Naisson et al. / https://cds.cern.ch/record/2712606?ln=fr