Engineering Developments

Towards Seamless Substrates

Joanna Święszek
KA on behalf of FCC SRF WP2 and CERN EN-MME Group

FCC Week
5-9 June 2023

FCC SRF WP2 : Towards 400MHz Manufacturing

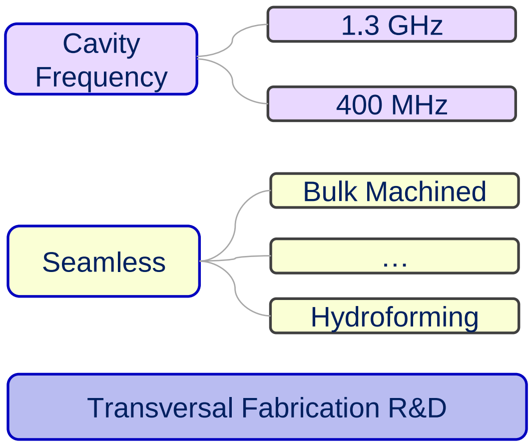
End goal is to **define fabrication route for cavities conform to CDR baseline** requirements. In order to do this:

- **Identify the best manufacturing strategy for 400MHz** in view of *RF performance*, *series production*
- **Through 1.3 GHz, supporting developments** of all SRF stakeholders

Focus on :

- Copper, as Nb Substrate
- Overall optimisation of welds : seamless equator (as baseline), fine tuning EB welding (iris)

Fabrication Program



1.3 GHz Monoblock

Reminder

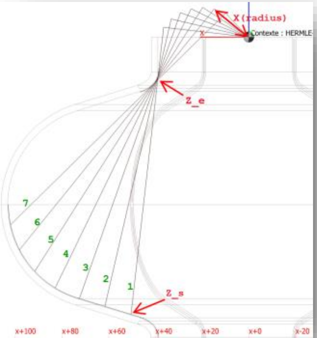
First bulk-machined monoblock cavity

Aim: provide monoblock as reference component for RF studies

Specific process definition for bulk machining:

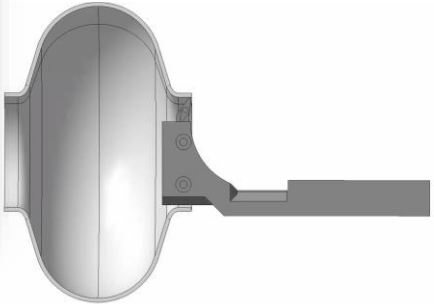
- Tool holder design & manufacturing
- CAM programming, machining simulation
- Diamond finishing

5-axis rough milling



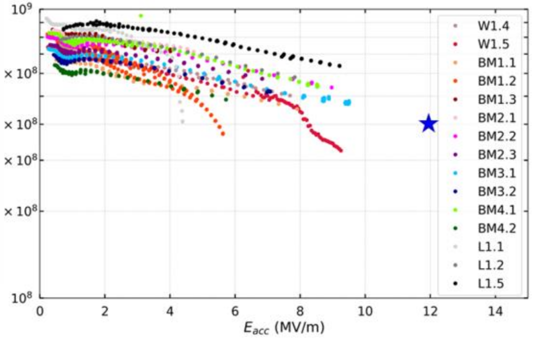
Courtesy: Karol Ścibor

Finishing turning of the inner cavity surface with a diamond



- Roughness Ra ~ 0.15 µm
- Max. internal shape deviation ~ 20 µm
- Wall thickness variations < 20 µm

Very good RF results!
Repeatable high-performance



Courtesy: L. Veg-Cid and A. Bianchi

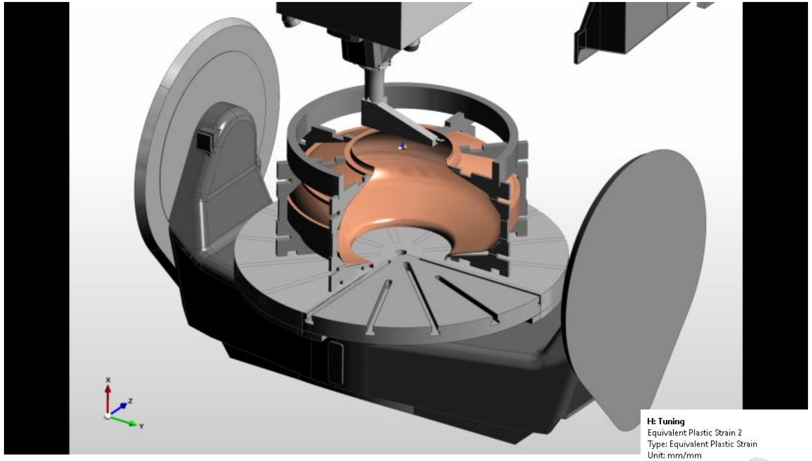
400 MHz Monoblock

Aim: provide monoblock as reference component for RF studies

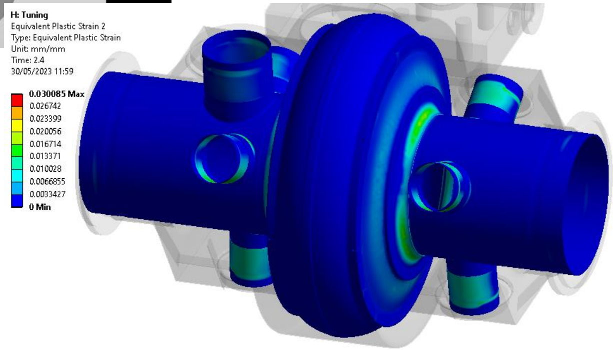
STATUS:

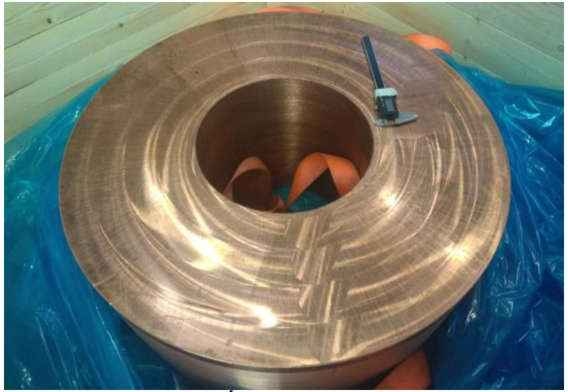
- **Cavity Loading Simulations and Design:** done
- **Fabrication process:** defined and simulated; trials ongoing on partial Aluminum dummy
- **Fabrication Tooling:** designed and under production
- **Cu OFE Material:** received and under qualification

- **Cut-offs :** under production



Courtesy: Alan Saillet



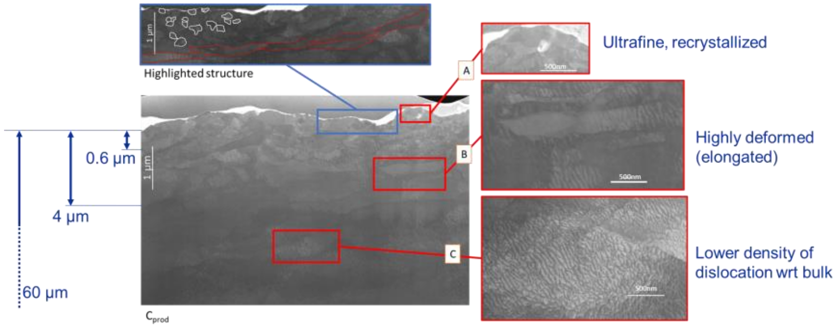


Courtesy: Karol Ścibor

R&D: Machining & Affected Surface Layer

Aim: master the **impact of machining on the surface layer**: and its influence on later coating performance

Study finalized for **turning**:

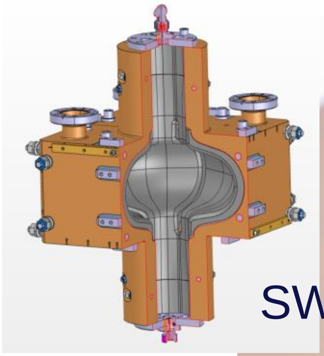


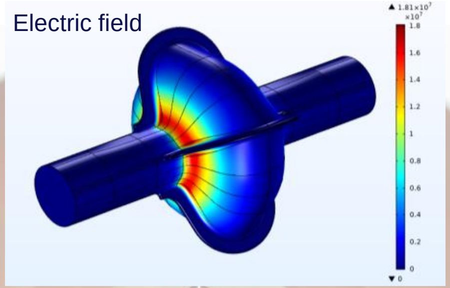
Experimental analysis of subsurface integrity during fine turning of OFE copper for radiofrequency cavity manufacturing
A. Camelin, P. Naisson, G. Poulachon, A. Dácunto, S. Atieh

Ongoing study for **milling**:

- Samples based on SWELL fabrication techniques
- Representing different machining scenarios
- DOE: Cutters, machining paths, cutting conditions

CERN Ref. : M. Garlasche', M. Kolenic

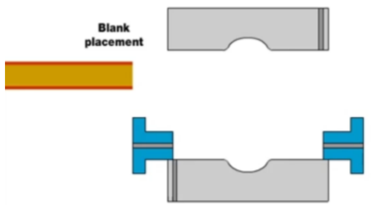




SWELL 1.3 GHz

SWELL progress and status
F. Peauger, M. Timmins

Hydroforming: Introduction



PAST: HF identified as suitable process for manufacturing seamless substrates.

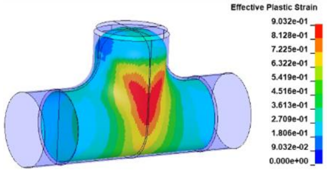
NOW: process optimization, minimizing number of steps, having:

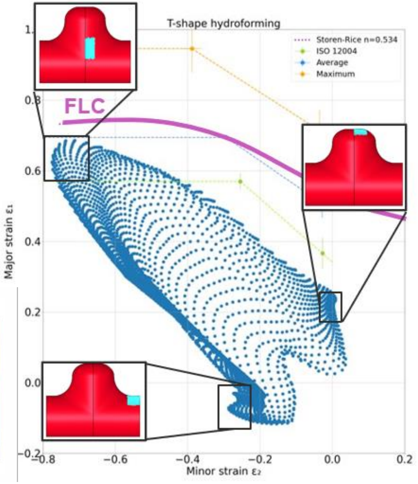
- ➢ reliable fabrication techniques
- ➢ advanced capabilities in process simulations (through FEM)
- ➢ novel material characterization
- ➢ **COLLABORATION**

R&D FEM vs experiment

Forming Limit Diagram
for failure prediction

1) Simulate
2) Corelate eps1 and eps2
3) Observe part deformation paths
4) Assess feasibility





CERN: *J. Święszek, A. Gallifa Terricabras, D. Smakulska, M. Garlasche', S. Atieh*

- Process guidelines
- Raw material and treatments definition
- Simulations

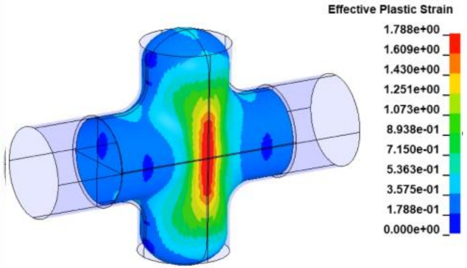
KEK: *A. Yamamoto, M. Yamanaka*

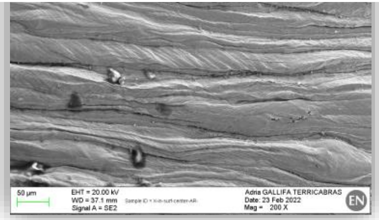
- Raw material procurement
- Tools design and manufacturing
- Hydroforming trials

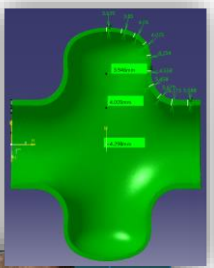
Collaboration CERN-KEK

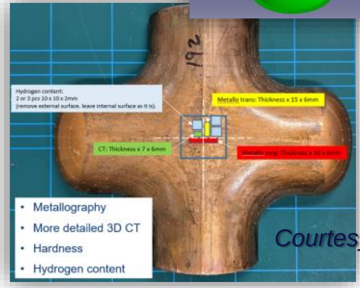
Hydroforming: Coupled FEM and experimental qualification

BENCHMARK PIECE
1) Hydroform
2) Measure
   - *3D Shape & deformed mesh*
   - *Thickness, roughness, hardness*
3) Benchmark with numerical simulations
4) Validation of the material model and failure criterion





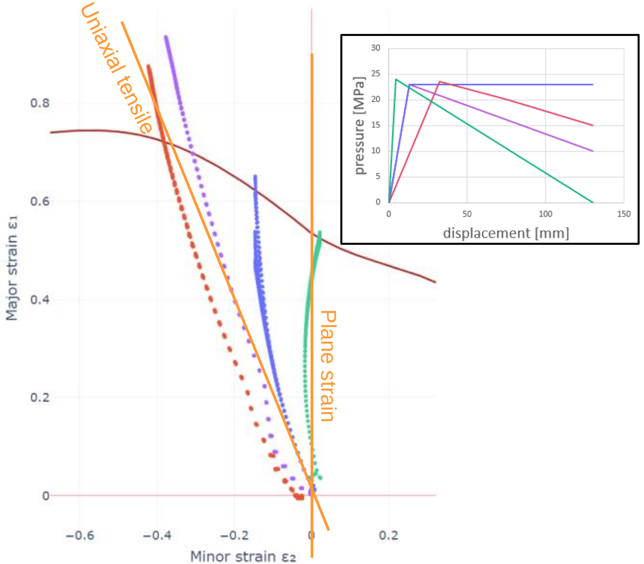




Courtesy: A. Gallifa Terricabras

5) Process parameter influence
6) Comparison of different hydroforming strategies
7) Process optimization
8) Process parameter (pressure vs displacement) definition

FLD with straining paths for a given set of process parameters



Formability highly dependent on the process parameters. **Optimization by simulations!**

Hydroforming: 1.3 GHz Cavity

Collaboration CERN-KEK

HYDROFORMING STRATEGIES

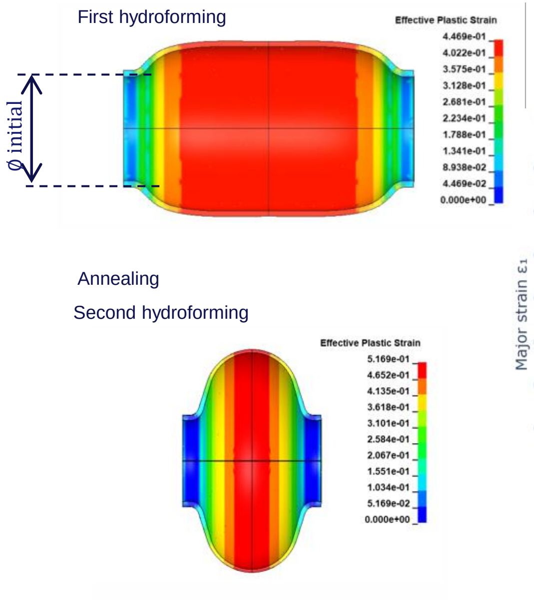
- Studied and optimized through simulations
- Based on detailed material characterization
- Verified against failure model

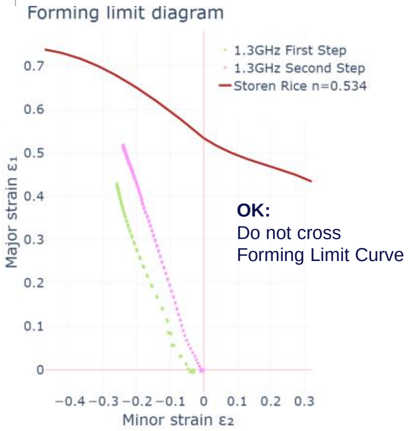
Both strategies are feasible with the material properties of tested Cu-OFE

Baseline

two-step Hydroforming

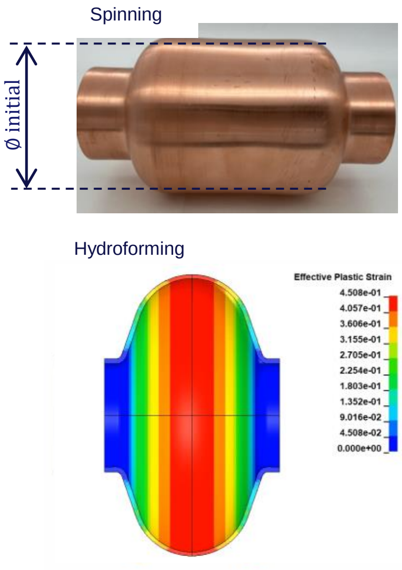
ONE intermediate heat treatment

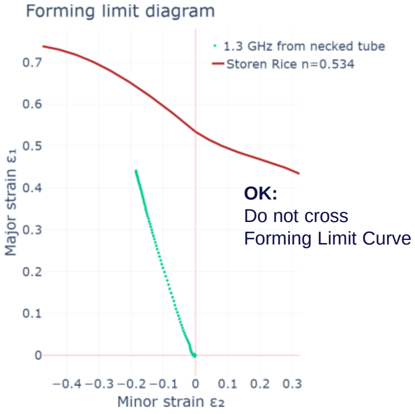




Necking + Hydroforming

NO intermediate heat treatment





Hydroforming: status

Collaboration CERN-KEK

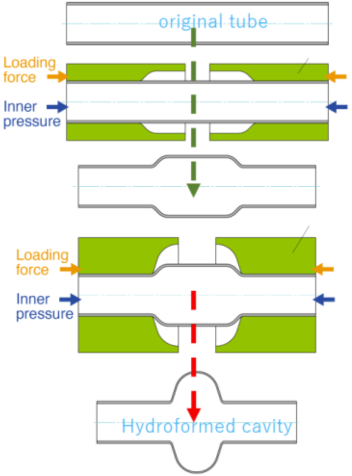
Baseline

two-step Hydroforming

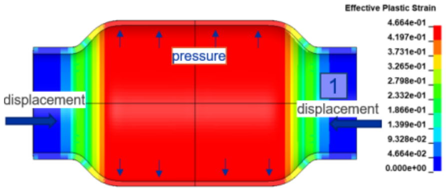
ONE intermediate heat treatment

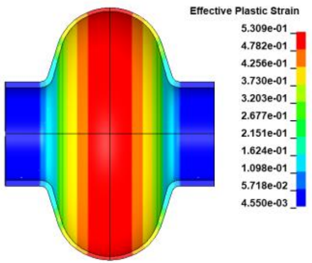
1.3 GHz

Successful hydroforming of 1.3 GHz cavity with only two expansion steps, feasibility and repeatability proved!

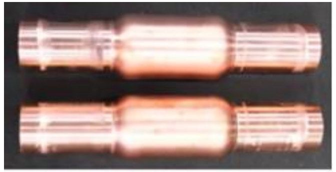


Defined by M. Yamanaka





Simulated by CERN

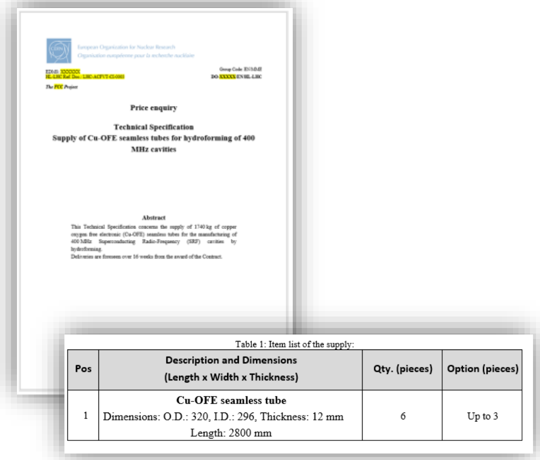


Courtesy: A. Yamamoto, M. Yamanaka

Produced by KEK

400 MHz

- **Raw material specified:** ready for procurement
- Hydroforming process strategy defined


Price enquiry

Technical Specification

Supply of Cu-OFE seamless tubes for hydroforming of 400 MHz cavities

Abstract

Table 1: Item list of the supply:

Pos	Description and Dimensions (Length x Width x Thickness)	Qty. (pieces)	Option (pieces)
1	Cu-OFE seamless tube Dimensions: O.D.: 320, I.D.: 296, Thickness: 12 mm Length: 2800 mm	6	Up to 3

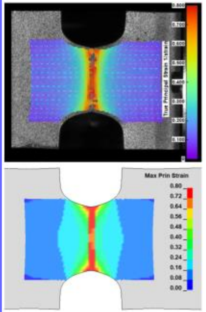
New Nb material for cost saving

A. Yamamoto, International Workshop on Future Linear Colliders

Hydroforming: Material studies

Material characterization as input for simulation (for given material batch):

- True strain stress curve
- Failure model

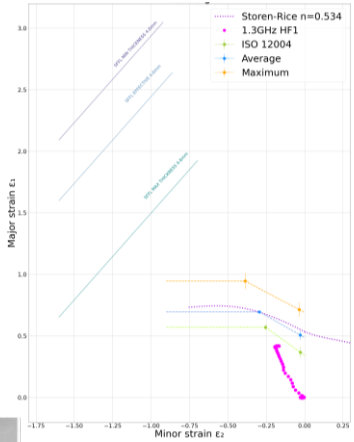


NOVEL APPROACH OF FAILURE FOR SRF APPLIATION: SRFLD

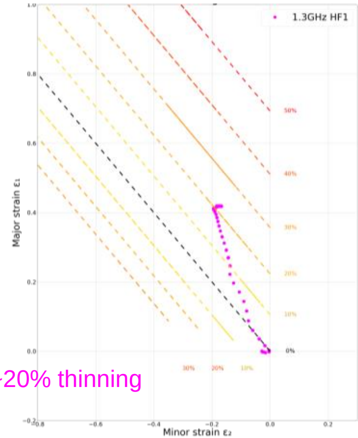
- **Evolving Forming Limit Diagram** to incorporate features of interest for SRF
- A tool for prediction of parameters of interest, both for fabrication and SRF (.. final surface roughness, wall thickness..)

Example of results from the numerical simulation plotted on SRFLD

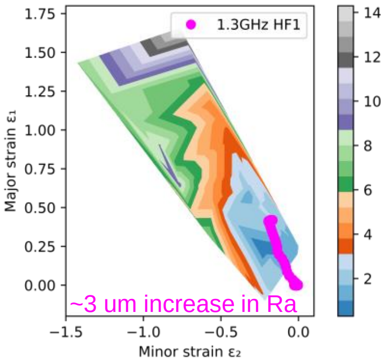
SFFL and FLC Cu-OFE



Thinning [%]

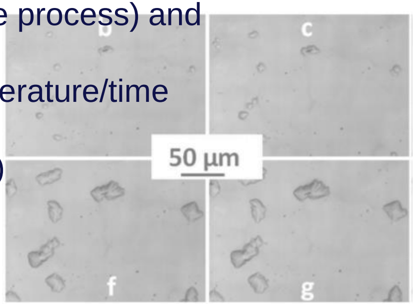


Roughness increase [um]



Material R&D activities for optimizing Nb coating:

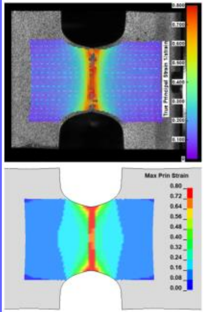
- Roughness studies (at different stages of the process) and roughness amelioration
- Optimization of the annealing process: temperature/time (microstructure optimization)
- Hydrogen content (avoid hydrides formation)



Courtesy: A. Gallifa Terricabras, G. Rosaz

Hydroforming: Material studies

Material characterization as input for simulation (for given material batch):
- True strain stress curve
- Failure model



NOVEL APPROACH OF FAILURE FOR SRF APPLIATION: SRFLD

- **Evolving Forming Limit Diagram** to incorporate features of interest for SRF
- A tool for prediction of parameters of interest, both for fabrication and SRF (.. final surface roughness, wall thickness..)

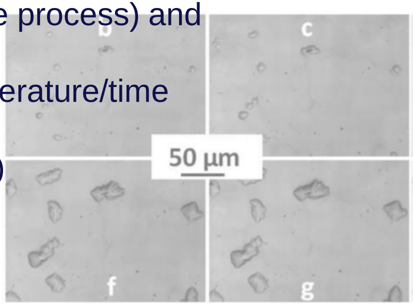
Very powerful tool that can be used for many large deformation processes for SRF fabrication

Regularly collecting data to improve the plots

Simulations and Characterization of Fabrication Processes for SRF
J. Święszek, A. G. Terricabras, D. Smakulska, M. Garlasché, SRF Workshop 2023
R&D and Numerical Simulations for SRF Fabrication Technologies
J. Święszek, A. G. Terricabras, B. R. Palenzuela, D. Smakulska, M. Garlasché, SRF Workshop 2022
Materials studies for SRF
A. G. Terricabras, M. Garlasché, B. R. Palenzuela, D. Smakulska, J. Święszek, SRF Workshop 2022

Material R&D activities for optimizing Nb coating:
- Roughness studies (at different stages of the process) and roughness amelioration
- Optimization of the annealing process: temperature/time (microstructure optimization)
- Hydrogen content (avoid hydrides formation)

Courtesy: A. Gallifa Terricabras, G. Rosaz



Presentation by Thomas

Conclusions

Abridged but coherent campaign ongoing, for **defining manufacturing route for FCC series cavities**

Seamless fabrication:

- 400 MHz bulk-machined will provide benchmark for downstream surface processes
- promising results from 1.3 GHz hydroforming campaign

Not forgetting **EB welding**!

- The EB deflector showed promising results on improving RF surface quality with respect to the old procedure (lower surface roughness, no polishing required)
- Experience gained during development for LHC spare cavities will be directly applicable to FCC
- Coming applications for LHC and FCC will be critical to determine if internal welding is a significant improvement for SRF performance

Fabrication R&D:

- CERN building know-how on main domains of interest for SRF mechanical fabrication
- …advanced process simulations, material and failure characterization (SRFLD,..), impact of fabrication processes on SRF requirements (machining of RF surfaces, …)

Thank you for your attention