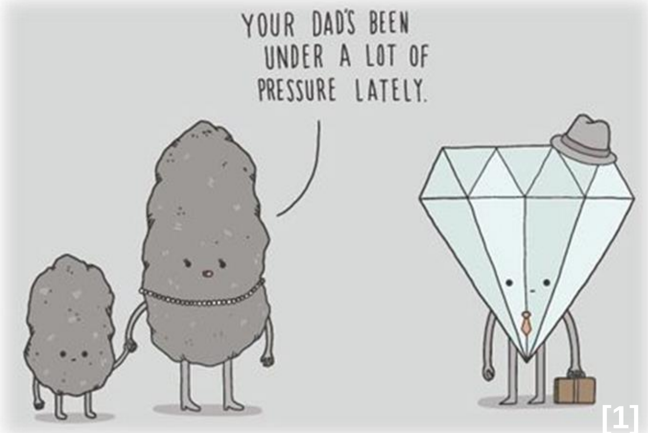
Hydroforming Elliptical SRF Cavities:
Studies on 1.3 GHz and Beyond

On behalf of FCC SRF Cavity Fabrication WP

A. Gallifa Terricabras, Marco Garlaschè, D. Smakulska, J. Swieszek and many others

FCCW2021 – 28th Jun ÷ 2nd Jul

Context



The Hydroforming process

Hydroforming @ CERN Workshop. Our Aim for the present and future:

- **Reclaim CERN know-how** on the process, for future applications
- Potential provider of **Cu substrates** for ongoing coating studies and beyond

An established acquaintance in the SRF world

- Established industry practice. No direct technology breakthroughs in the last years

Why this resurgence of interest?

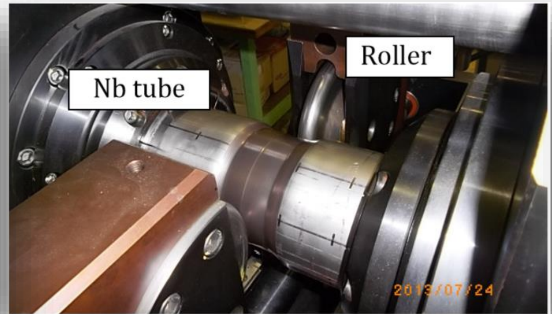
- **Enhanced capabilities all around**: manufacturing control, characterization, and acquisition
- Embedding novel **numerical simulations** for process modelling

Content

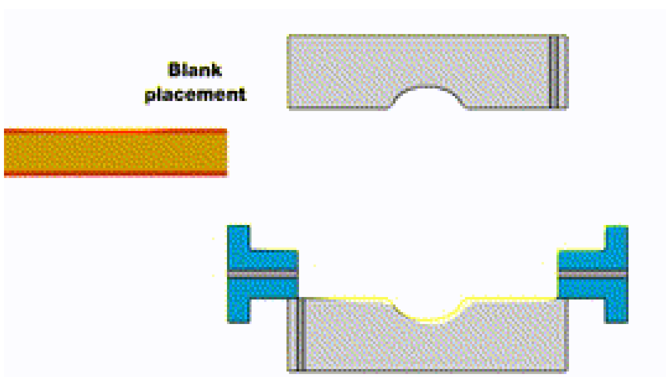
- Introduction on Hydroforming for SRF Elliptical Cavities
  - Advantages and Challenges

- R&D Campaign (simulations, tests)
  - T- and X-Bulged Tube *(KEK Collaboration)*
  - Elliptical Monocell Cavities: 400 MHz to 1.3 GHz

Hydroforming for SRF Elliptical Cavities



Initial Tube → Necking → Anneal → Hydroform ⟳ Anneal

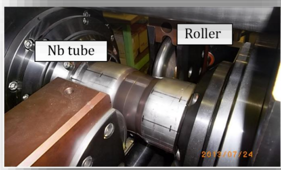


[2]

Main **advantages**

- Reduce number of welds (equator)
- Low cost and lead time for series

Hydroforming for SRF: Challenges



Initial Tube

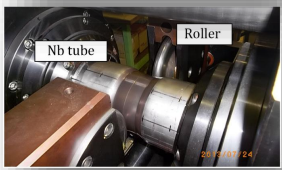
- Raw material: seamless **tube availability**, **reliability** (dimensional tolerances, surface conditions)

Necking

Hydroform

- **Reliability** of process

Hydroforming for SRF: Challenges


Initial Tube

Necking

Hydroform

- Raw material: seamless **tube availability**, **reliability** (dimensional tolerances, surface conditions)
- Reliable suppliers for seamless OFE Tubes
- Over-thickness + Turning

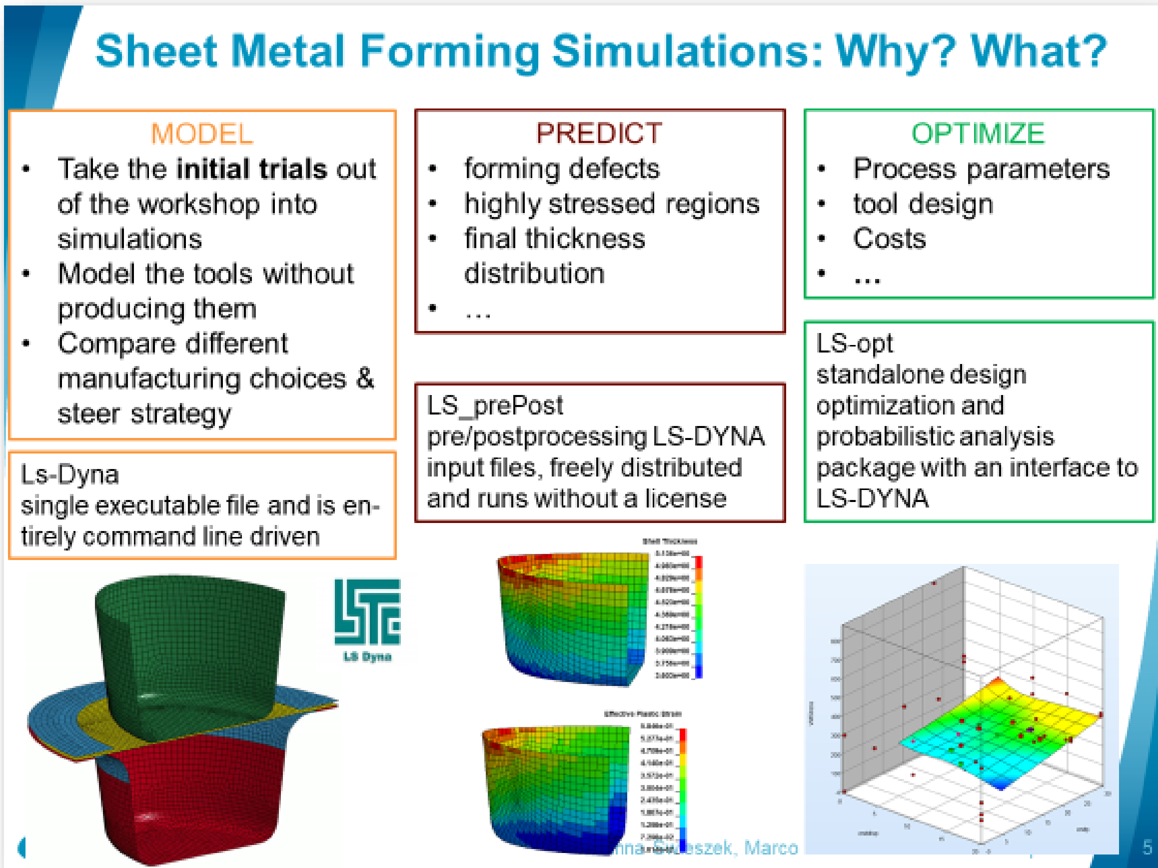
- **Reliability** of process
- Suppliers with state of art **know-how** on process and its control

Initial **fixed costs. Containment** through:

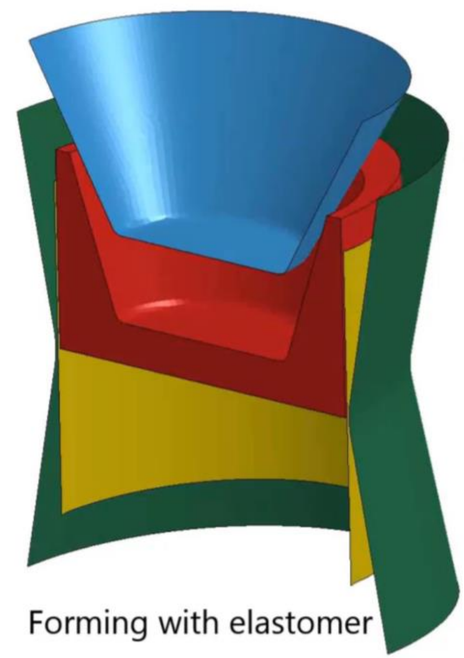
- Going to industry for main processes
- **Numerical Simulations**, to optimize overall fabrication strategy…. Minimize straining of material, less fabrication steps, less thermal treatments

Shaping Process Optimization: FEM

- F.E. simulations and numerical optimization tools
- Taking **trials out of the workshop**
- **Reducing process cycles** to final cavity



REF: J. Swieszek SRF Workshop @CERN 2019

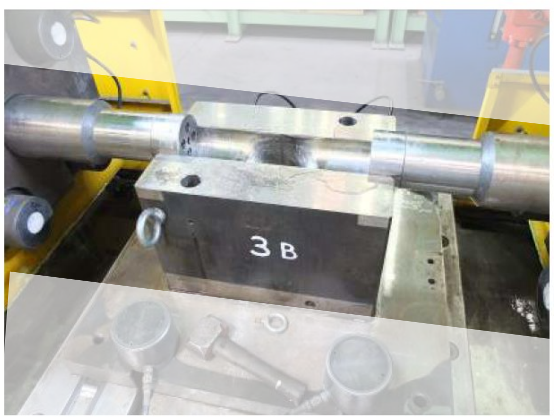


Forming with elastomer

Sims VS. Reality : T-Bulged Tube

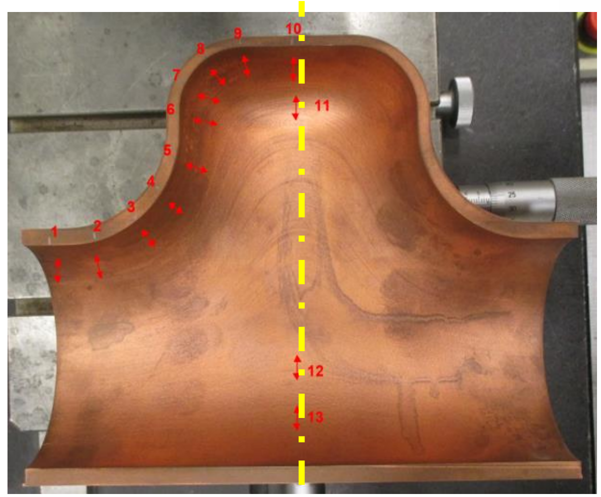
A benchmark for our simulations (hydroforming, CU OFE,..)

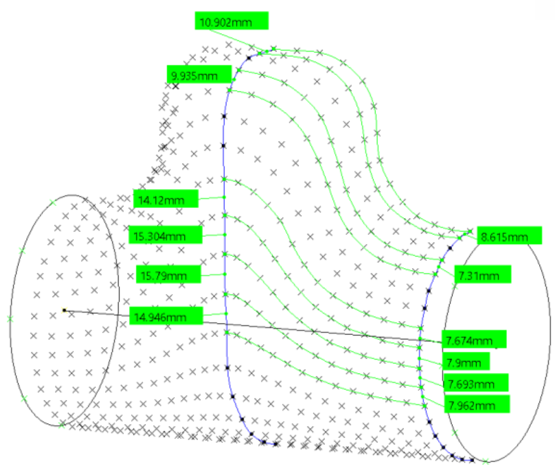
*1) **Hydroform***



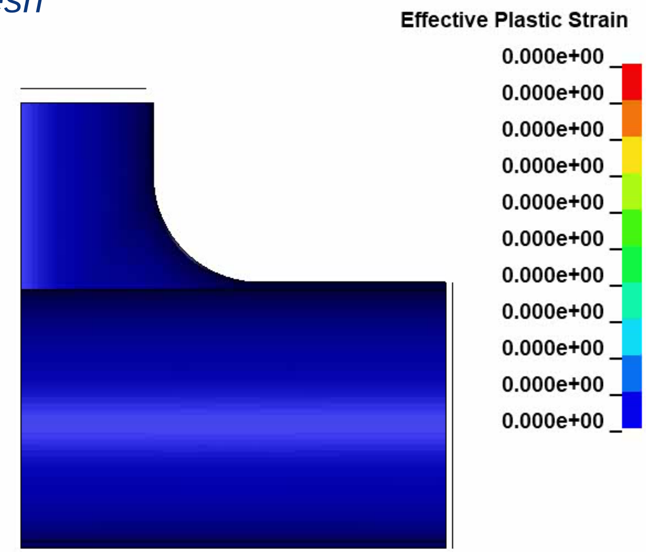
*2) **Measure** :*

- *Deformed 3D Shape & surface mesh*
- *Thickness, Roughness*



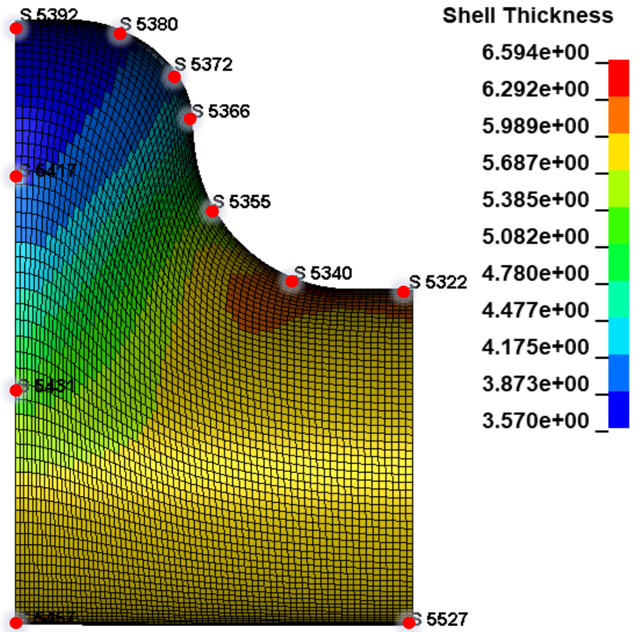


*3) **Simulate & Compare***



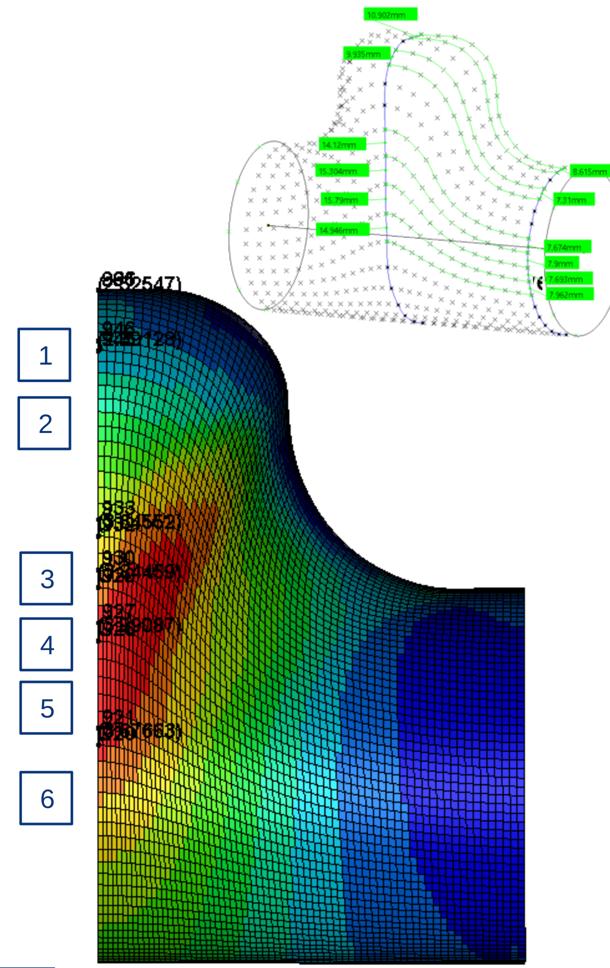
Collaboration with KEK
A. Yamamoto, M. Yamanaka

Highly Accurate Results



Comparing **thickness** at various notable positions

Average error ~ 4%

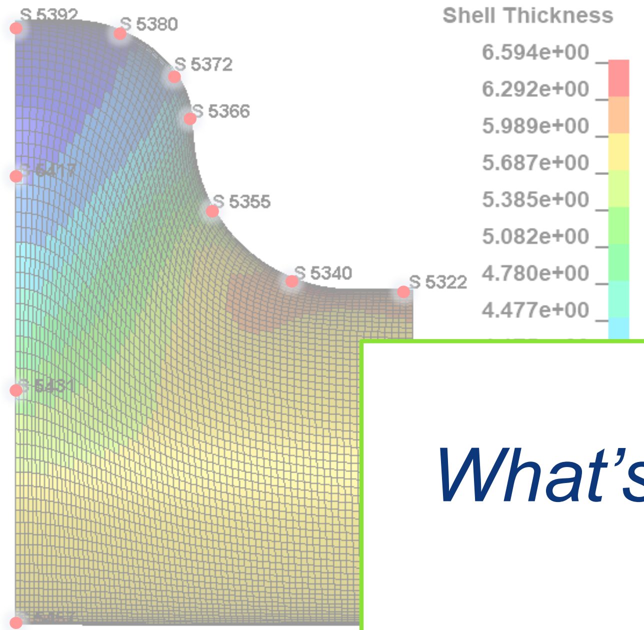


Azimuthal strain values:
Allows easy comparison for 'coincident' mesh elements between test piece & simulation

Average error ~ 3%

Point ID	ε Test	ε Sim
1	0.27	0.27
2	0.42	0.35
3	0.84	0.83
4	0.94	0.92
5	1.05	1.00
6	0.87	0.84

Highly Accurate Results



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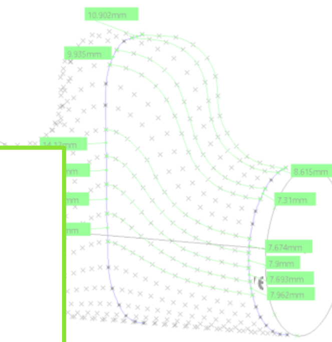
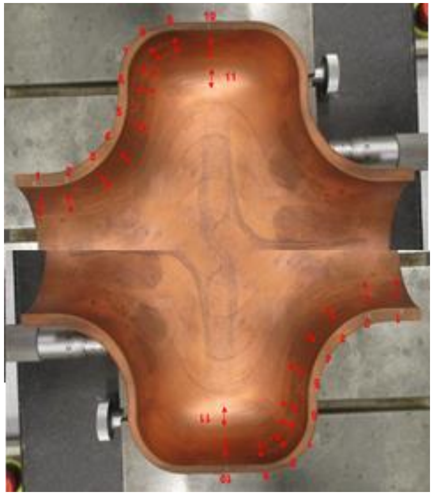


What's Next ?

X-Bulge fabrication test

To be compared with further advanced simulations



Azimuthal strain

Allows easy comparison for 'coincident' mesh elements between test piece & simulation

Average error ~ 3%

2	0.42	0.35
3	0.84	0.83
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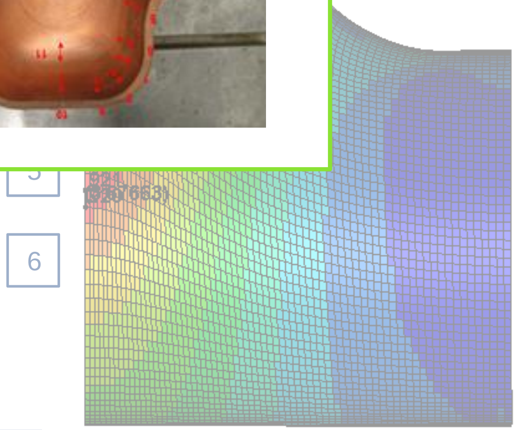
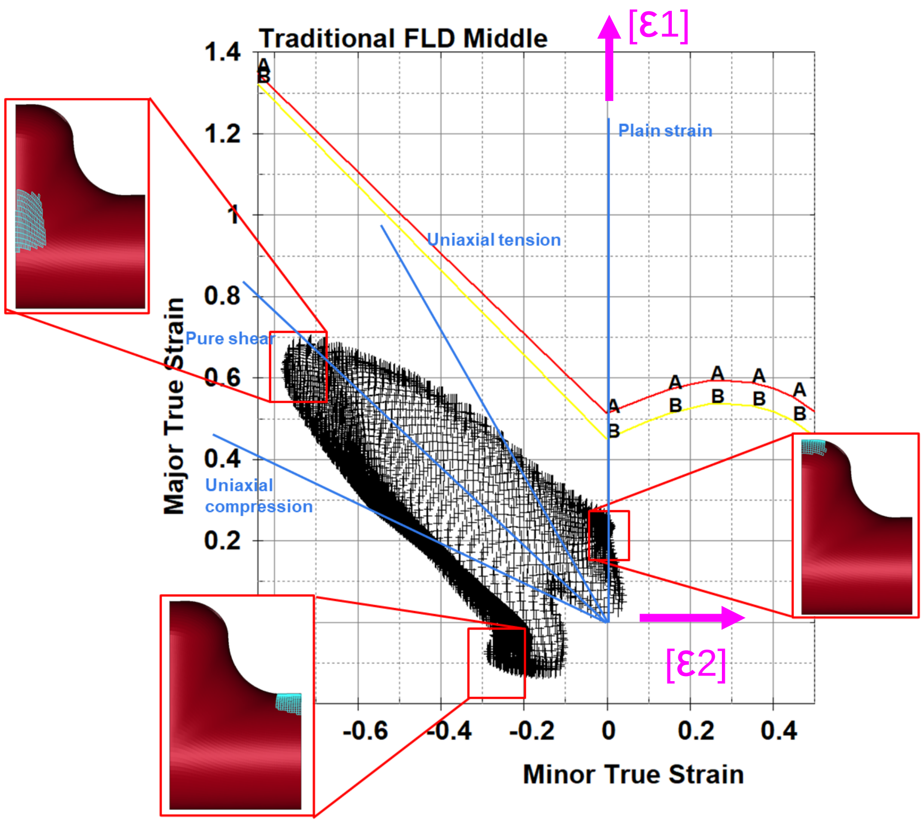


SRF Hydroforming: a Failure Model

- **Simulation** performance
- **Material** Model

- **Failure Model** : maximum strain criteria (Distortion Energy, Forming Limit Diagram)

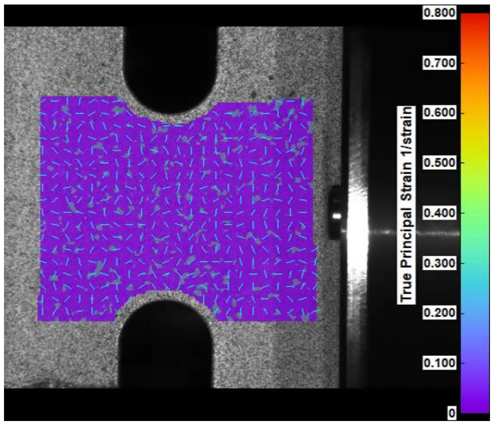


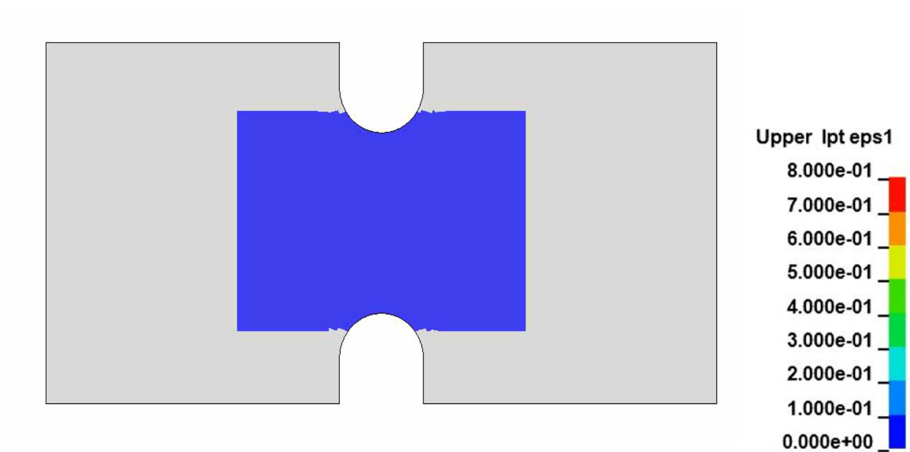
Many thanks to J-F Croteau (EASITrain) !

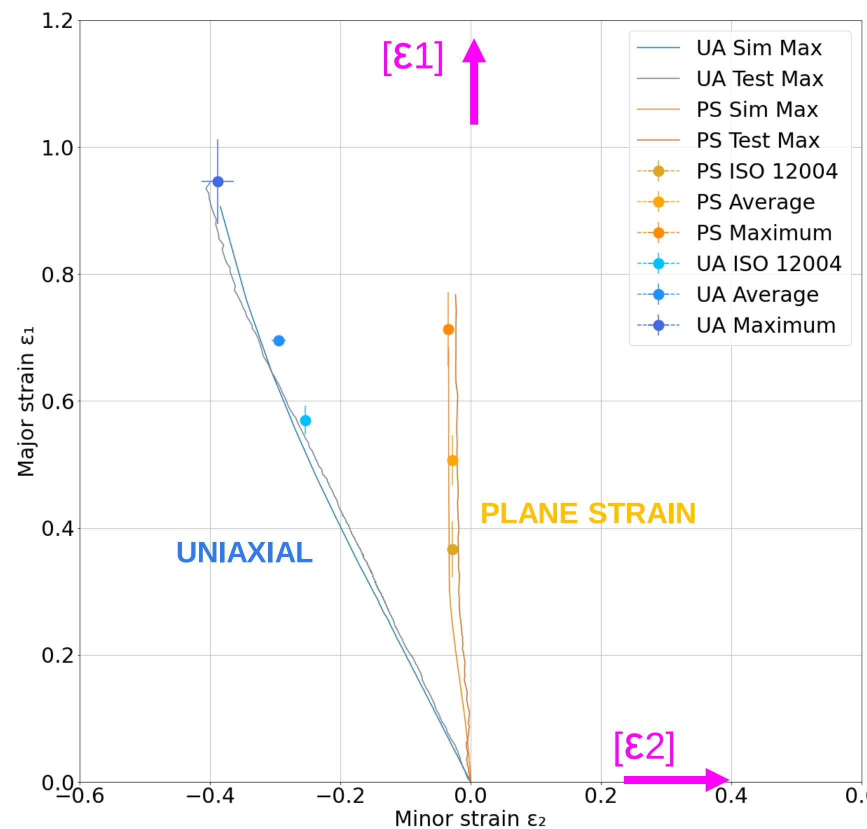
SRF Hydroforming: Experimental FLD

New simulation & experimental campaign @ CERN

Uniaxial & Plane stress tests → different criteria for max allowable strain



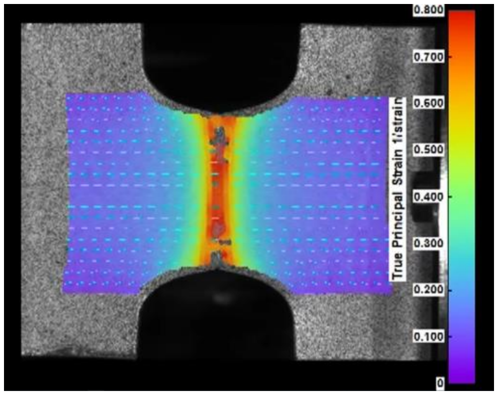


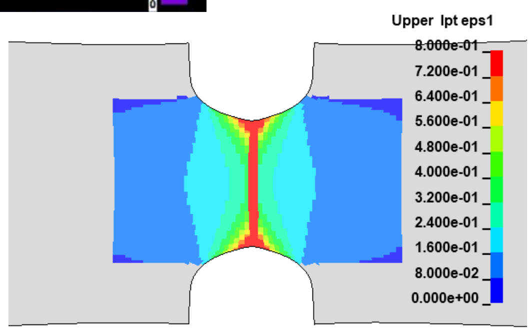


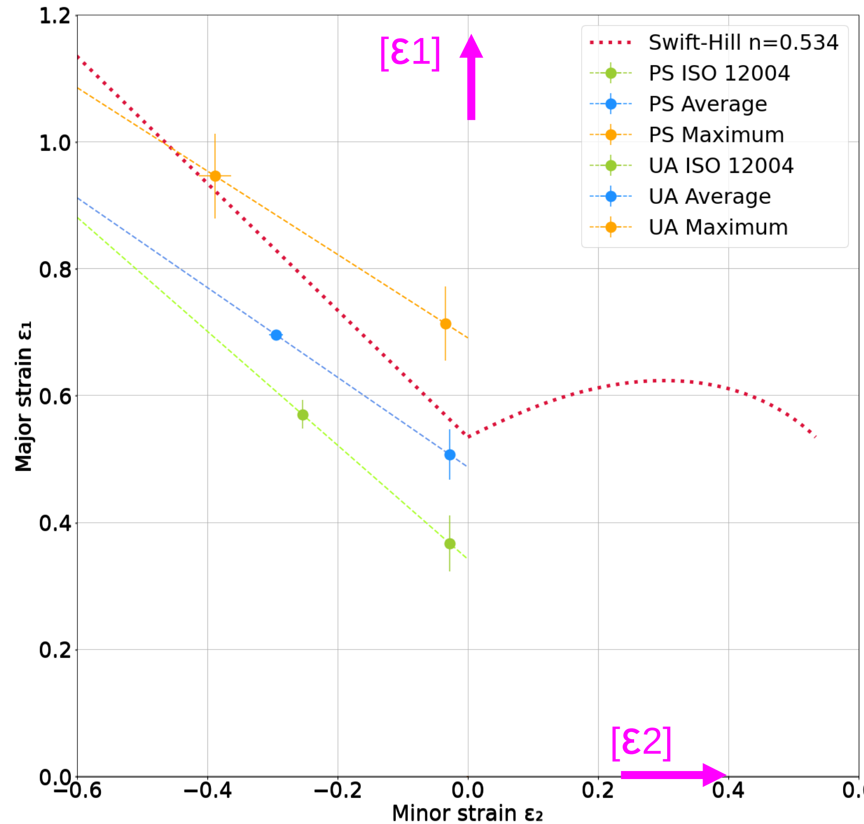
SRF Hydroforming: Experimental FLD

New simulation & experimental campaign @ CERN

Uniaxial & Plane stress tests → different criteria for max allowable strain







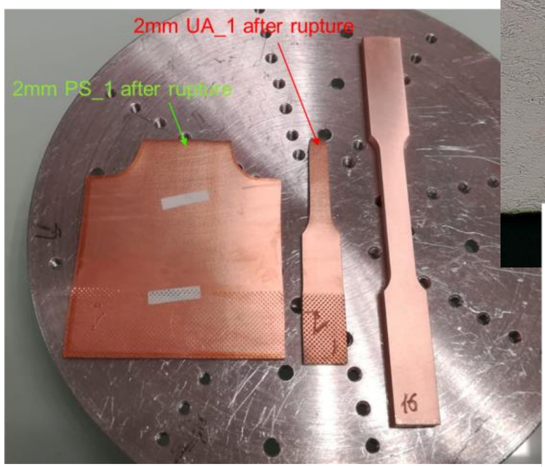
Why?

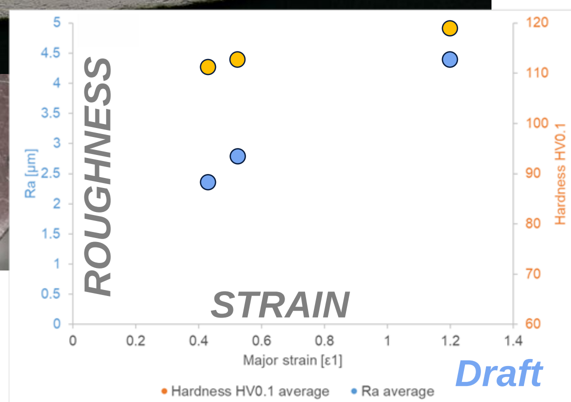
- Focusing on thicknesses nearer to hydroformed tubes
- Qualify new design for FLD-testing, compatible with CERN test infrastructure
- **Other failure aspects**…

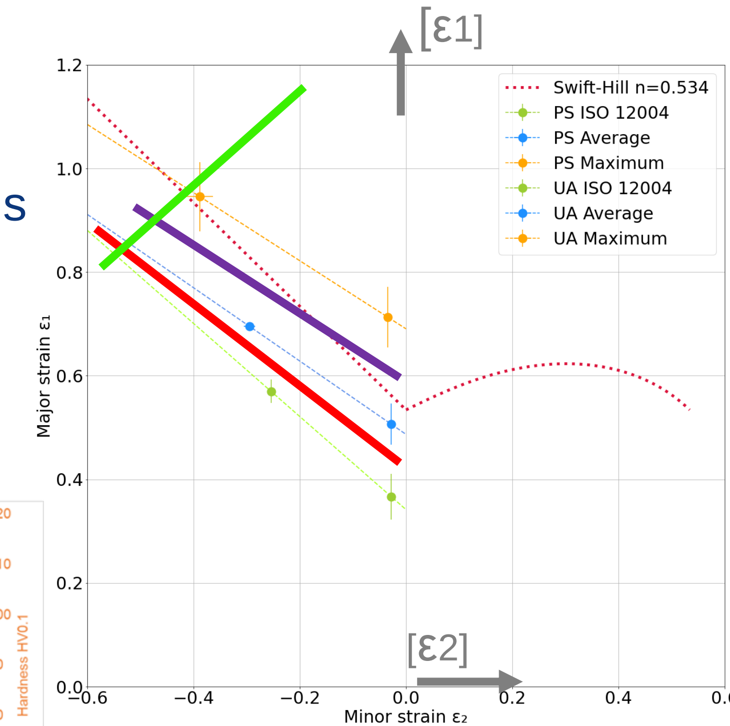
Other failure aspects…SRF²LD!

Specific SRF **Failure criteria** being checked:

- Onset of critical thinning
- Roughness and general surface degradation
- Presence of surface microcracks, shallow voids







Further failure modes to be checked

- Presence of surface pollutants (organic, metal)
- Hydrogen content, inclusions, sub-damaged layer

Many thanks to W. Venturini, G. Rosaz, L. Marques Antunes Ferreira

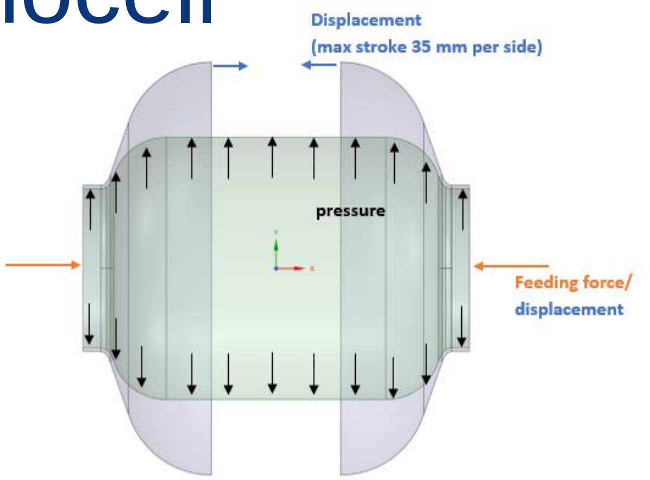
Content

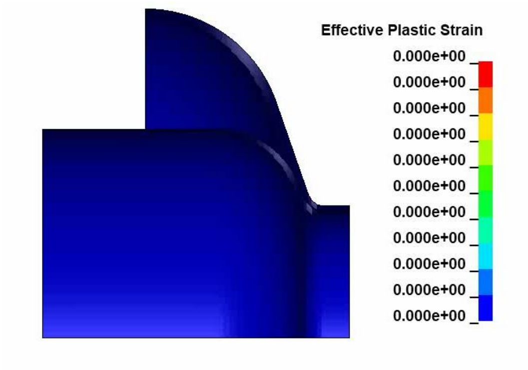
- Introduction
  - Hydroforming for SRF Elliptical Cavities
  - Challenges: to Hydroform or not to?
- R&D Campaign (simulations, tests)
  - T-Bulged Tube
  - Elliptical Monocell Cavities: 400 MHz to 1.3 GHz

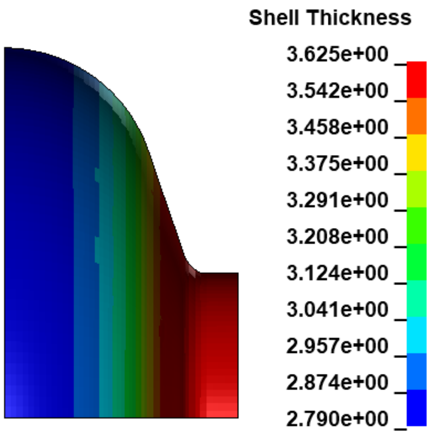
1.3 GHz Cavity Monocell

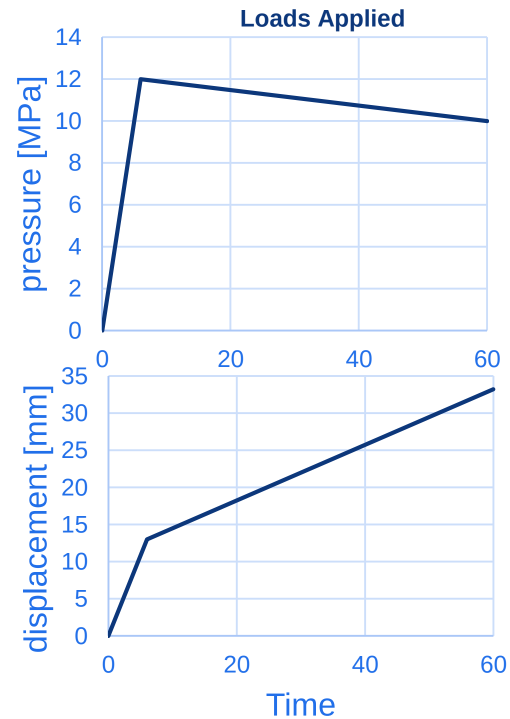
Process strategy definition by CERN. Baseline :

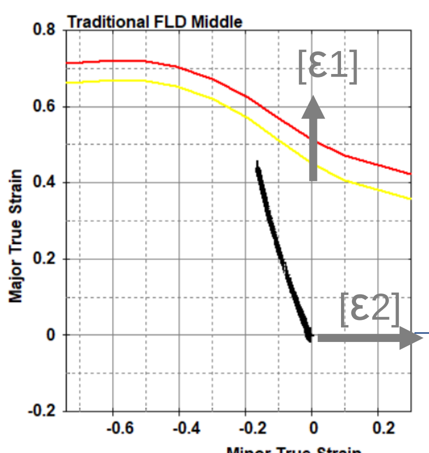
- Necking of straight tube
- Hydroforming to final geometry in just one step
- Die displacement and Internal pressure:
    - Specific values, applied simultaneously
- **No Intermediate Annealing**











1.3 GHz : Test Campaign Status

Initial Tube

- **Material @ CERN**
- Properties check on material batch: ongoing
- Remachining to size

Necking

- **P.O. Launched**
- Discussion ongoing on details of test campaign
- Spinning tools being designed

Anneal

- [Dream Scenario: Annealing not needed]

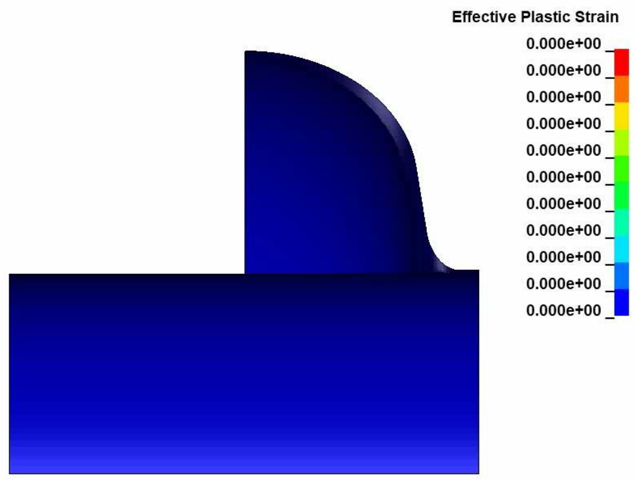
Hydroform

- Fabrication process parameters defined (& feasible)
- Supplier identification ongoing

Anneal

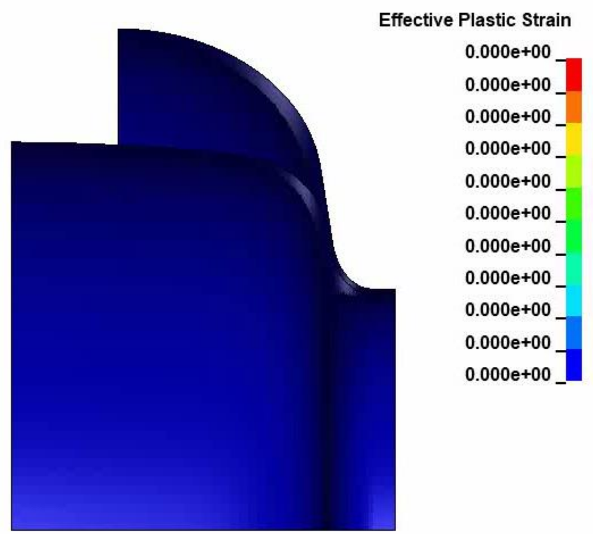
600 MHz Cavity Monocell: Process Sims

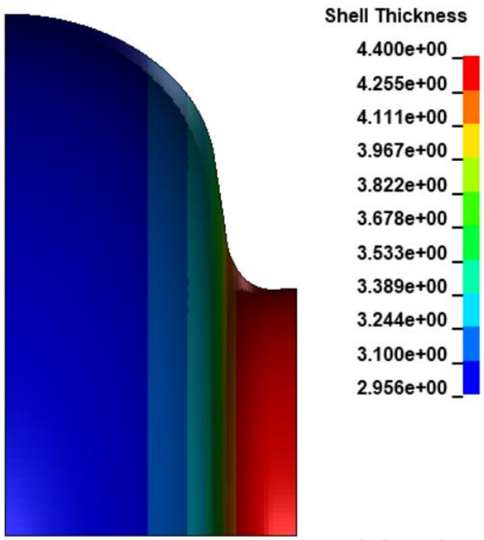
Many thanks F. Peauger



- **Hydroforming ONLY**
- From tube to final geometry **in two steps**
- Intermediate annealing

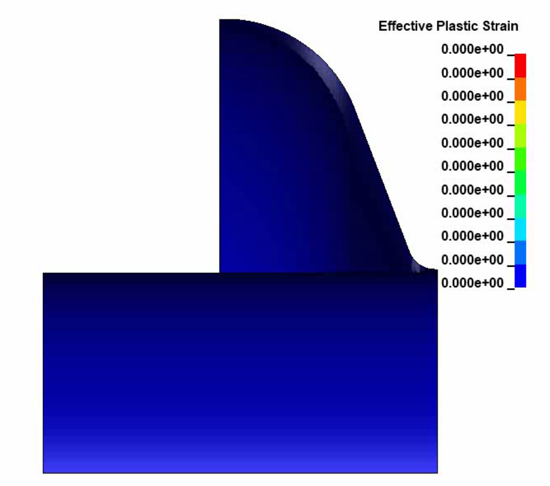
- Initial **tube**, **standard** from industry :
  - OD 216.6 mm, thck. 4.3 mm
  - L ~ 500mm



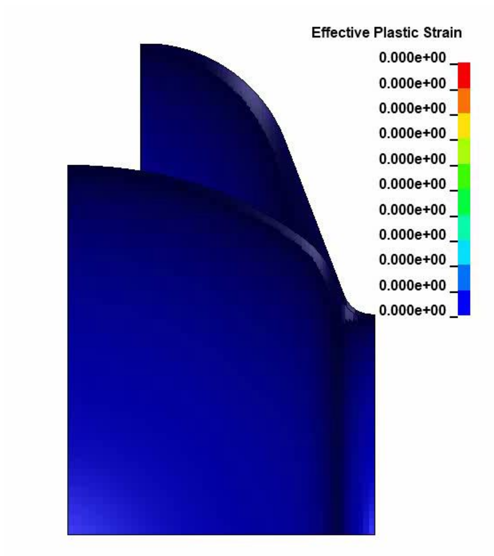


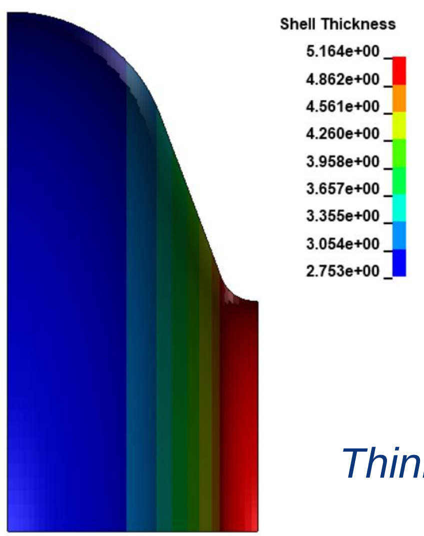
Thinning ~ 33%

400 MHz Cavity Monocell: Process Sims



- **Hydroforming ONLY**
- From tube to final geometry in two steps
- Intermediate annealing
- Initial tube, standard from industry :
  - OD 311 mm, thck. 5.5 mm
  - L ~ 600mm
  - **LIMIT!**





Thinning ~ 50%

Conclusions

Enhanced capabilities all around hydroforming. Most of past challenges can be tackled through:

- State of art process simulations
- Industrial partners

Numerical simulations for hydroforming:
- Building on established previous knowledge
- Validated on T-bulge

1.3GHz / 600MHz / 400MHz Cavities:
- Our target: from tube to cavity in two steps
- Always aiming at the industrially feasible

Ongoing activities:
- X-Bulge fabrication trial to be compared with further advanced simulation
- Bespoke material failure for SRF (”SRF2LD”)
- 1.3 GHz trials launched

Thanks for your Attention!