C. Pira, O. Azzolini, G. Keppel

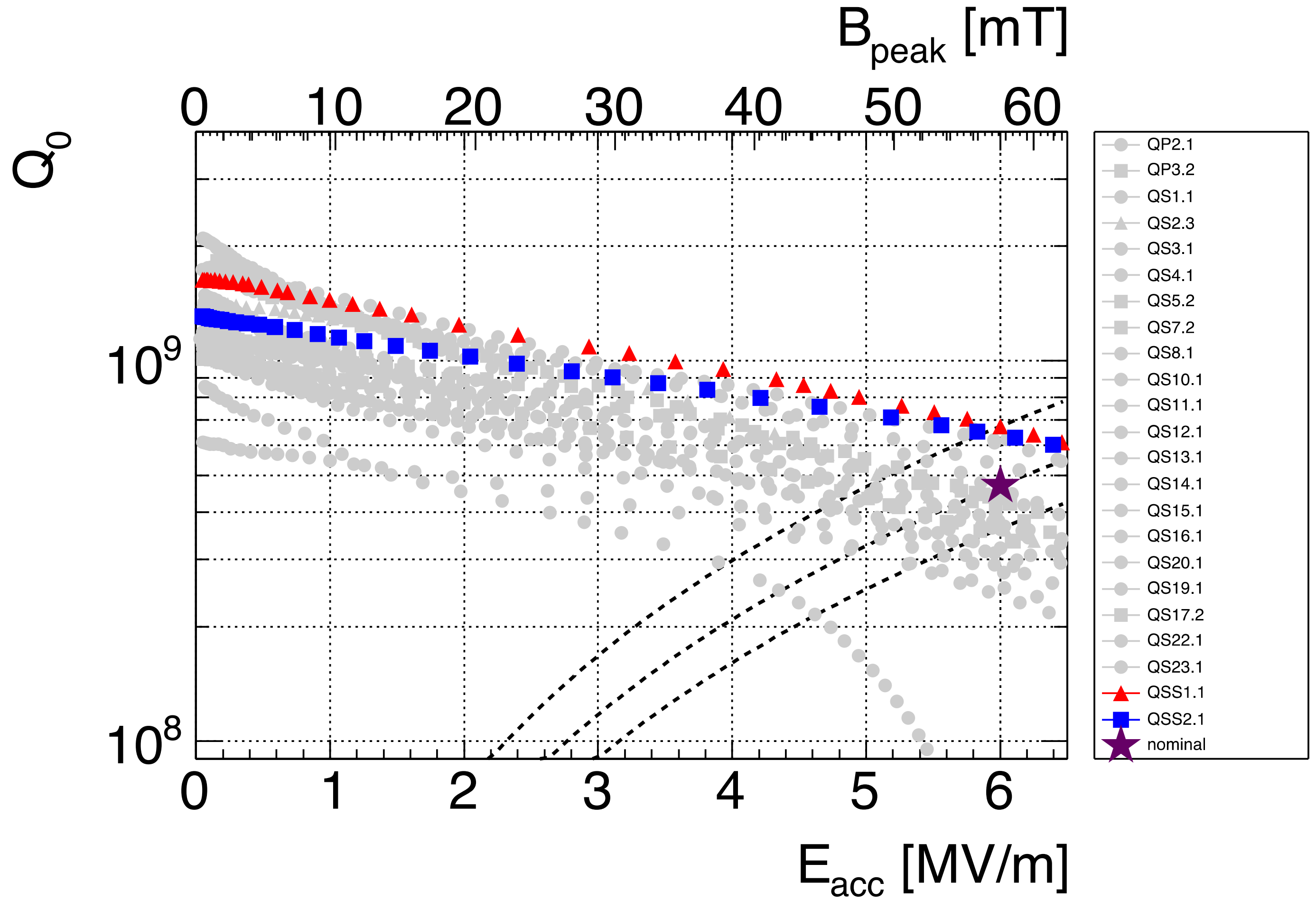
# R&D of Seamless elliptical cavities

Work performed under the CERN-INFN-STFC Agreement N. KE2722/BE/FCC

INFN
LNL
Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Legnaro

# Advantages of seamless cavities

- **Cheaper**
- **Avoid defects and irregularity of welding seams**
- **Increase RF performances** *(real examples of ALPI @ INFN and HIE-ISOLDE @ CERN)*

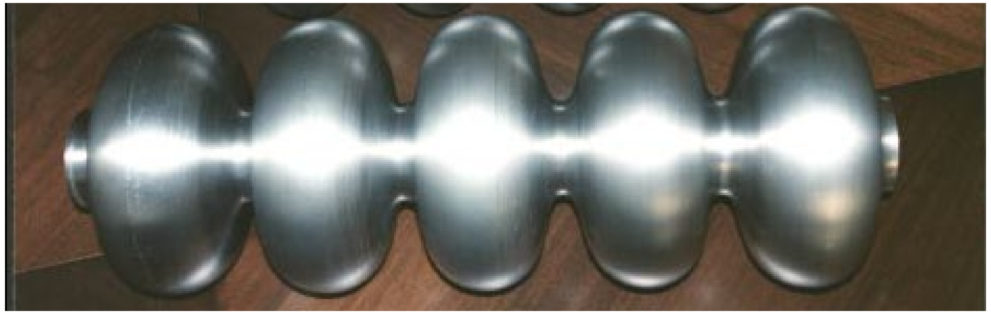



HIE ISOLDE two seamless cavities performance at 4.5 K

Courtesy of Walter Venturini

# Seamless cavities by spinning

- Hydroforming, explosive forming, **electroforming**, **electrodeposition** and spinning are the principal techniques explored for the production of seamless elliptical cavities
- LNL have a long experience in spinning of 1,3 and 1,5 GHz elliptical cavities
- In the framework of FCC studies spinning of 400 Mhz has been explored



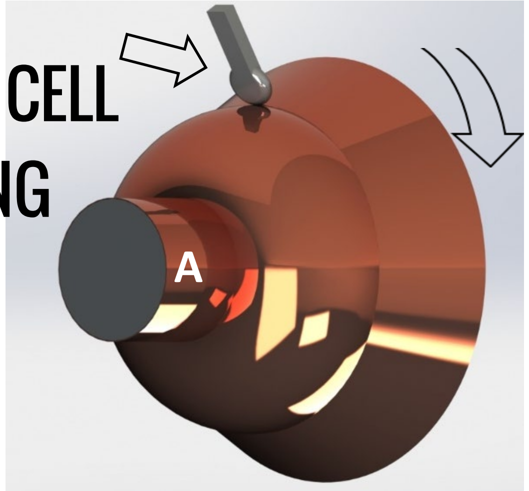
*First seamless multicell by spinning*

# Spinning production steps

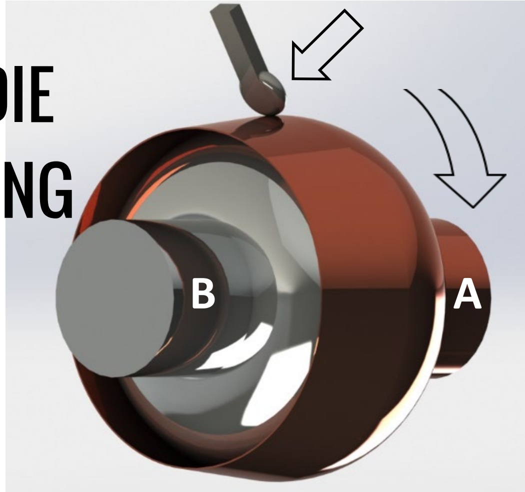
## Step 1
COPPER PLATE PREPARATION

## Step 2
DEEP DRAWING

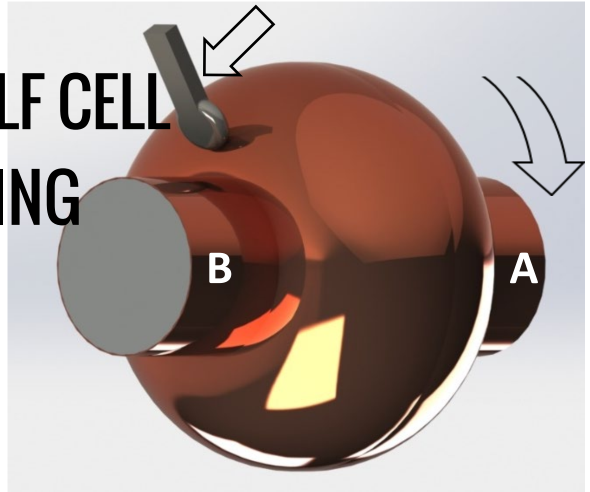
## Step 3
1st HALF CELL SPINNING



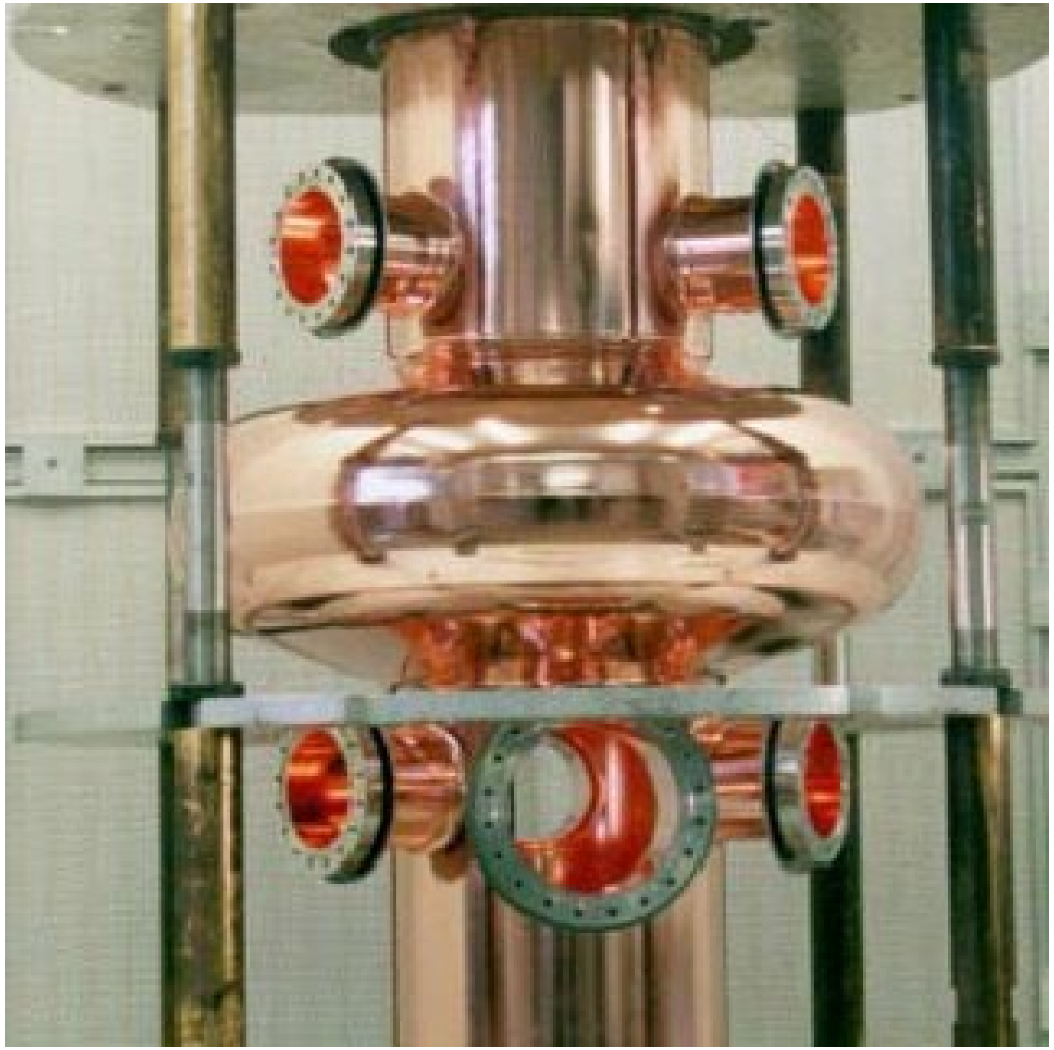

## Step 4
CONE DIE SPINNING

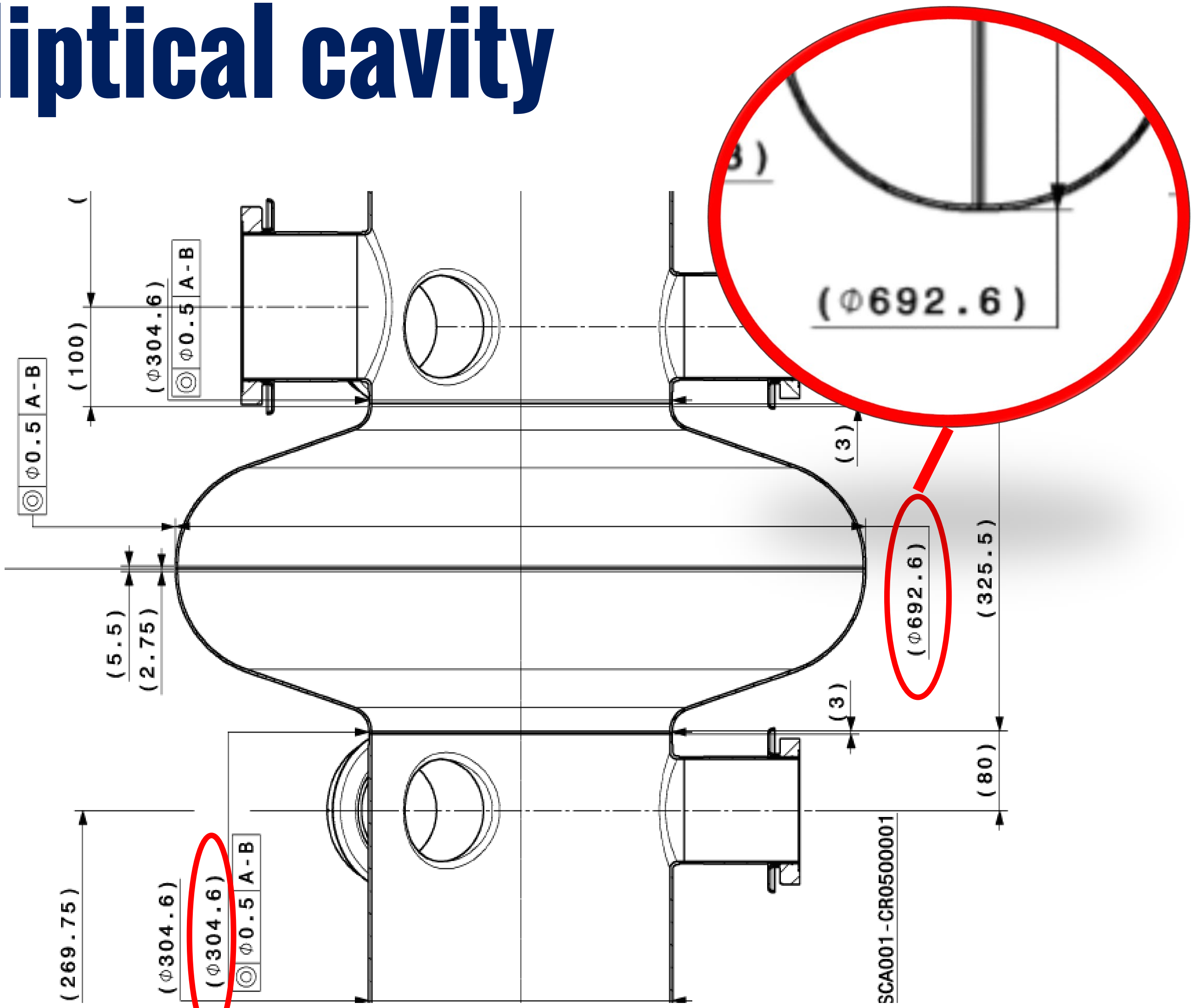



## Step 5
2nd HALF CELL SPINNING



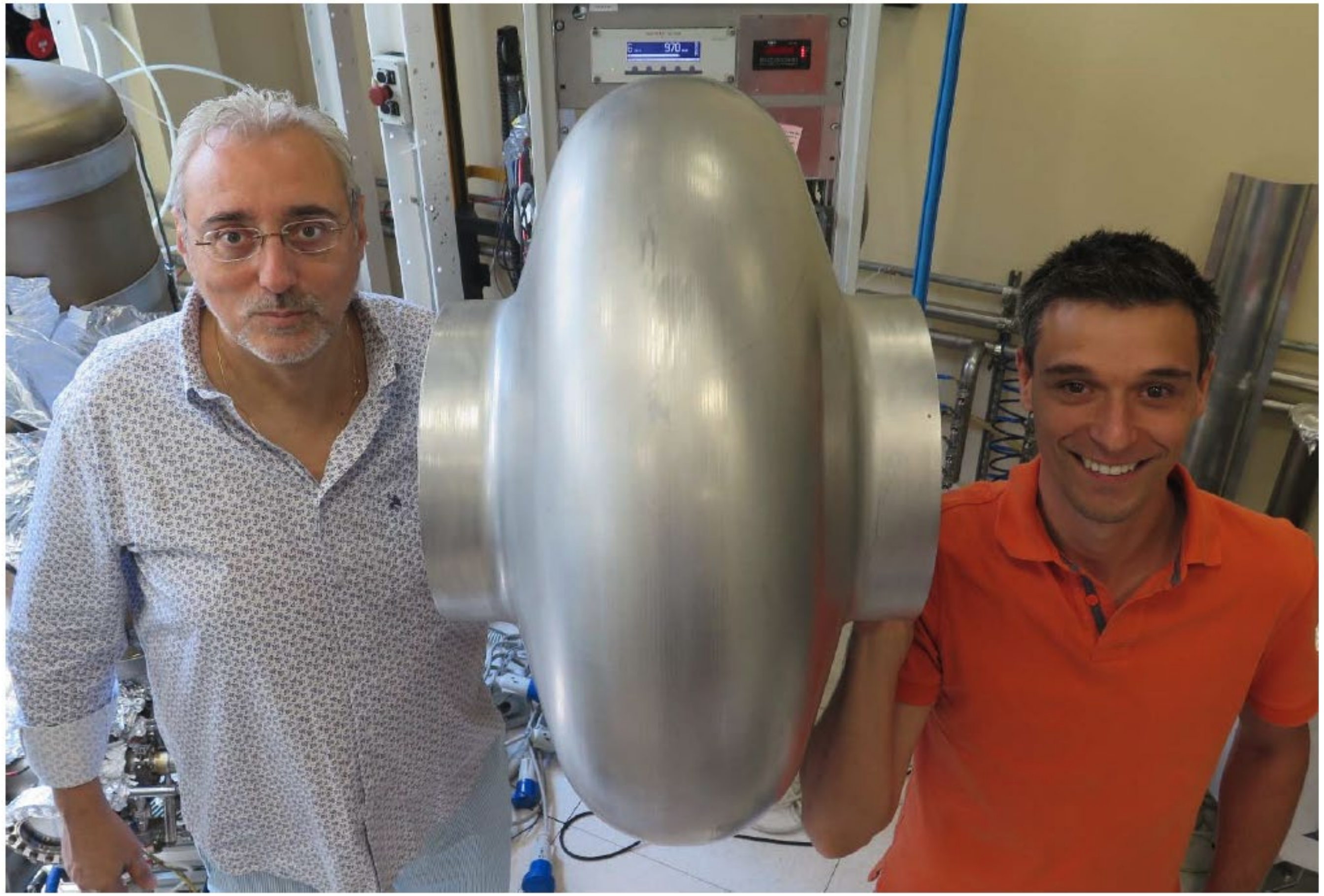
# 400 MHz eliptical cavity






S. Bauer et al., TEST RESULTS OF SUPERCONDUCTING CAVITIES PRODUCED AND PREPARED COMPLETELY IN INDUSTRY, Proceedings of EPAC 2004, Lucerne, Switzerland.

# STEP 0: Tool for 400 MHz cavity spinning
# July 2017, from Palmieri's R&D



*400MHz Seamless Aluminum Cavity prototype*

1. Copper sheets Ø 1150 mm
2. First half cell die (Iron)
3. Intermediate conical die (Nylon)
4. Second half cell Die (Nylon)

# STEP 1: OFE Copper sheet

- Dimension out of standard
- Difficulties to provide a cold rolled sheet
- **Thermal treated** (Hardness HV = 46)
- Received @ LNL on June 2018

Abnahmeprüfzeugnis DIN EN 10204-3.1
Inspection Certificate DIN EN 10204-3.1

mkm
we live copper

Besteller / Purchaser:

CERN
ORGANISATION POUR LA RECHERCHE

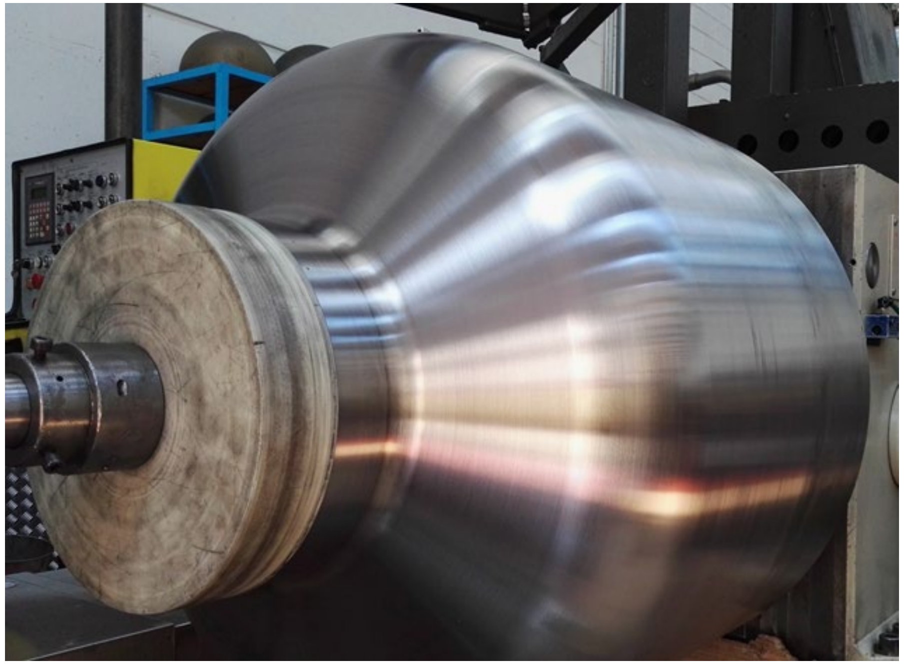
1211 Geneve
CH

MKM Mansfelder Kupfer und Messing GmbH
Lichtlöcherberg 40
06333 Hettstedt / Germany
Produktbereiche Bleche / Bänder
Überprüft nach AD 2000-Merkblatt W0/TRD100
durch den TÜV Hannover/Sachsen-Anhalt e.V.
Zertifiziert nach Richtlinie 97/23/EG durch die
TÜV CERT-Zertifizierungsstelle für Druckgeräte der
TÜV Nord Gruppe, Notifizierte Stelle, Kenn-Nr.: 0045
phone: +493476892473
fax: +493476892403
e-mail: Tom.Burchert@mkm.eu

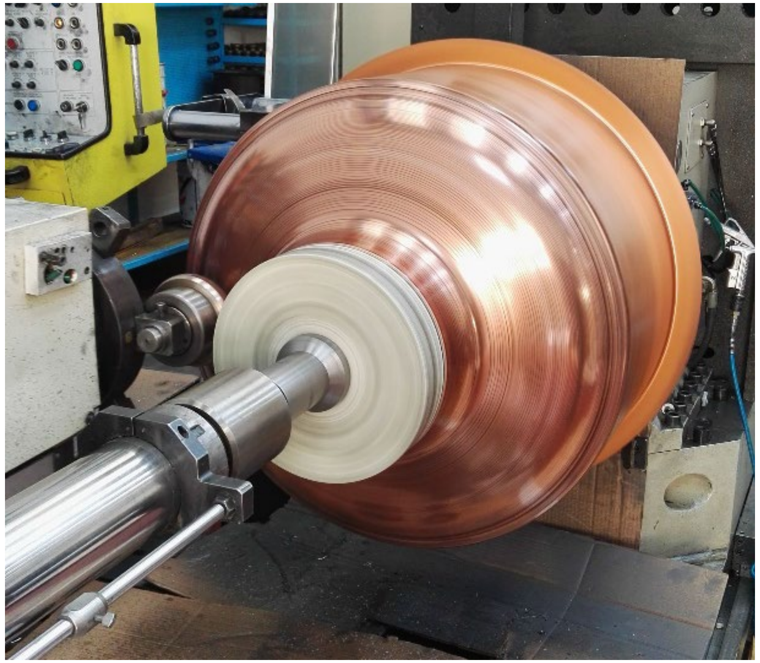
# STEP 2 Deep Drawing

IRON DIES


# STEP 3 Spinning of 1st Half Cell



IRON DIE



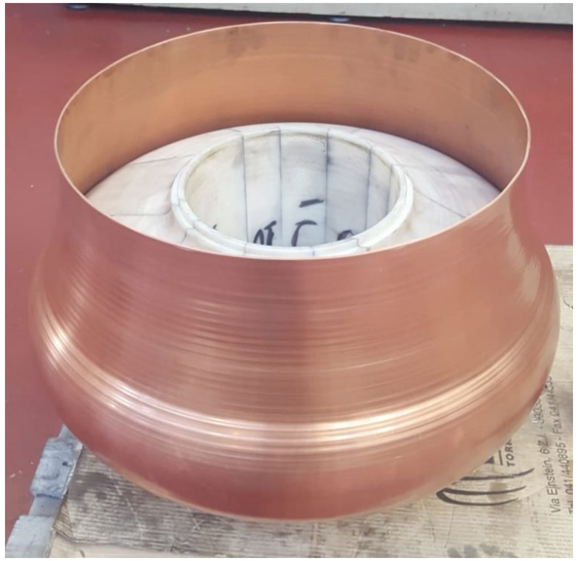
SPINNING OF THE FIRST HALF CELL

FIRST HALF CELL SPUN

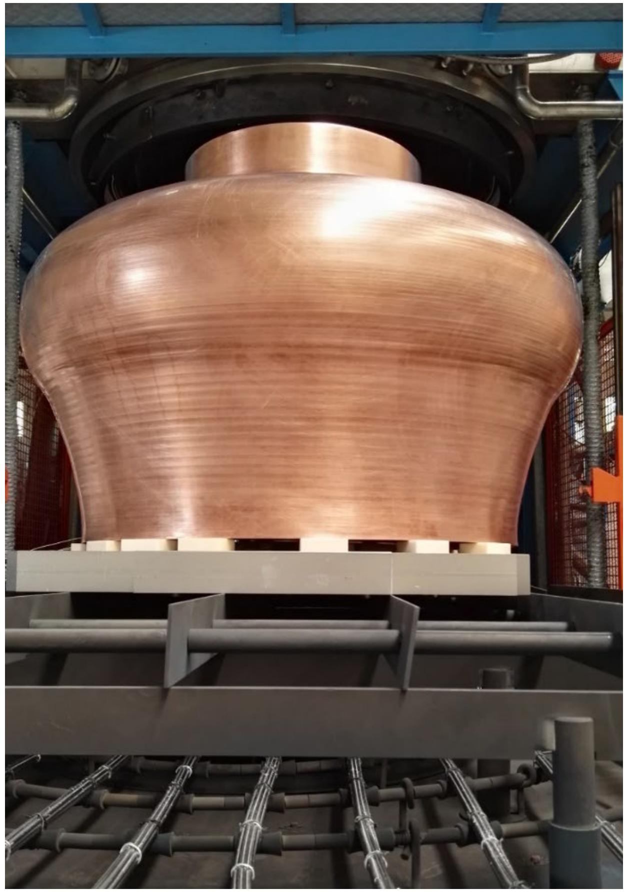
- No thermal treatments are necessary for the spinning of the 1° half cell

# STEP 4 Spinning of the intermediate conical die

NYLON CONICAL DIE



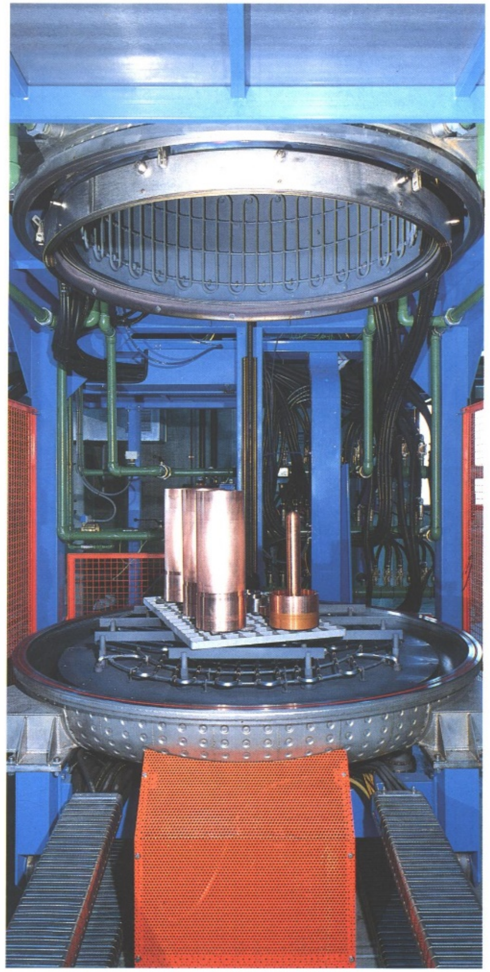
LOW SPINNABILITY



FIRST THERMAL ANNEALING

- A **thermal treatment** **is necessary** for the spinning of the conical die

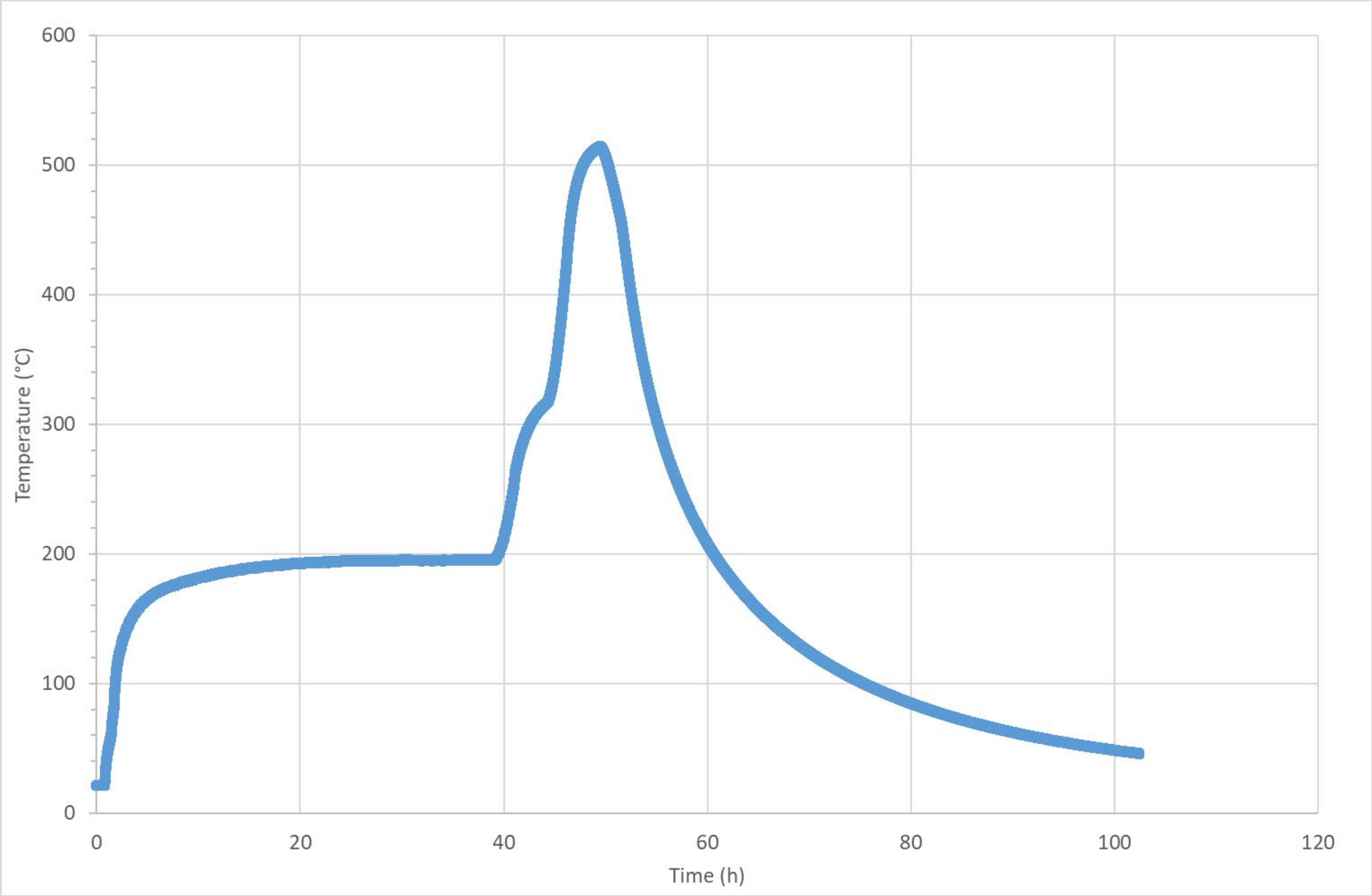
# Thermal annealing



## UHV Furnace @ LNL

- Maximum mass to be loaded: 1000 kg
- Nominal vacuum conditions for routine treatments: $5x10^{-5}$÷$1x10^{-6}$ mbar
- Lowest achievable base pressure: $10^{-7}$ mbar
- Maximum operational temperature: 1300°C
- Useful maximum diameter of components to be treated: 1300 mm
- Maximum height of components to be treated: 1600 mm
- Useful volume: around 2 $m^3$
- With height expansion (option): maximum height 2100 mm, maximum volume ~3 $m^3$
- Access: vertical loading with lifted platform
- Quick load cooling by argon/nitrogen inlet and dedicated heat exchanger

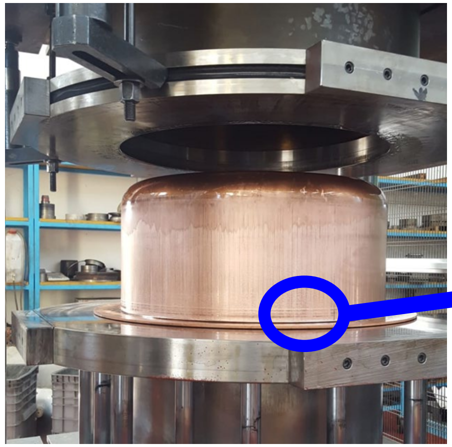
# Thermal annealing



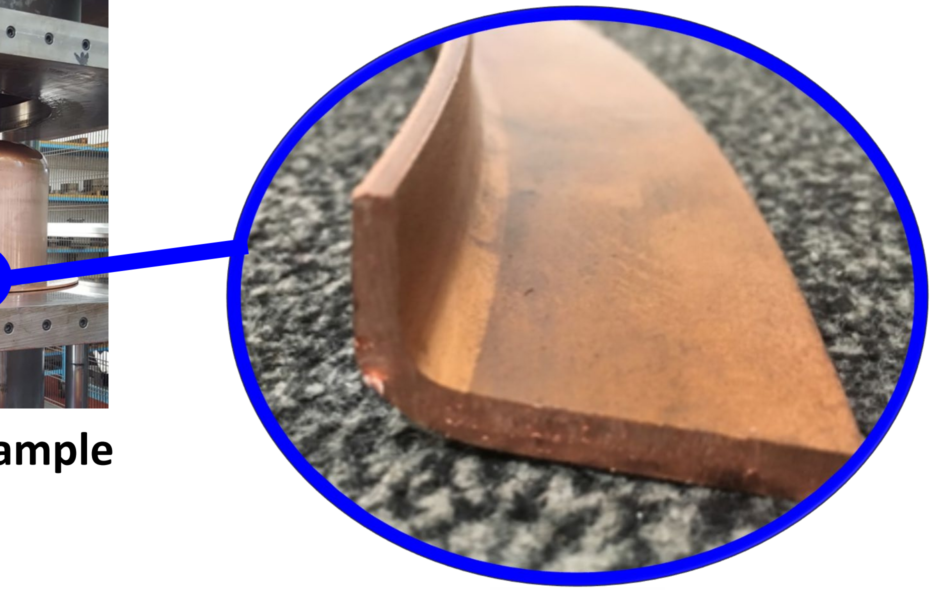

## Thermal Cycle (4 Days):

- Degassing at 200 °C 24h
- Thermal treatment **at 300 °C** for 3h
- Thermal treatment **at 500 °C** for 2h

# Test Sample for Grain Size Measurement



Deep drawing sample

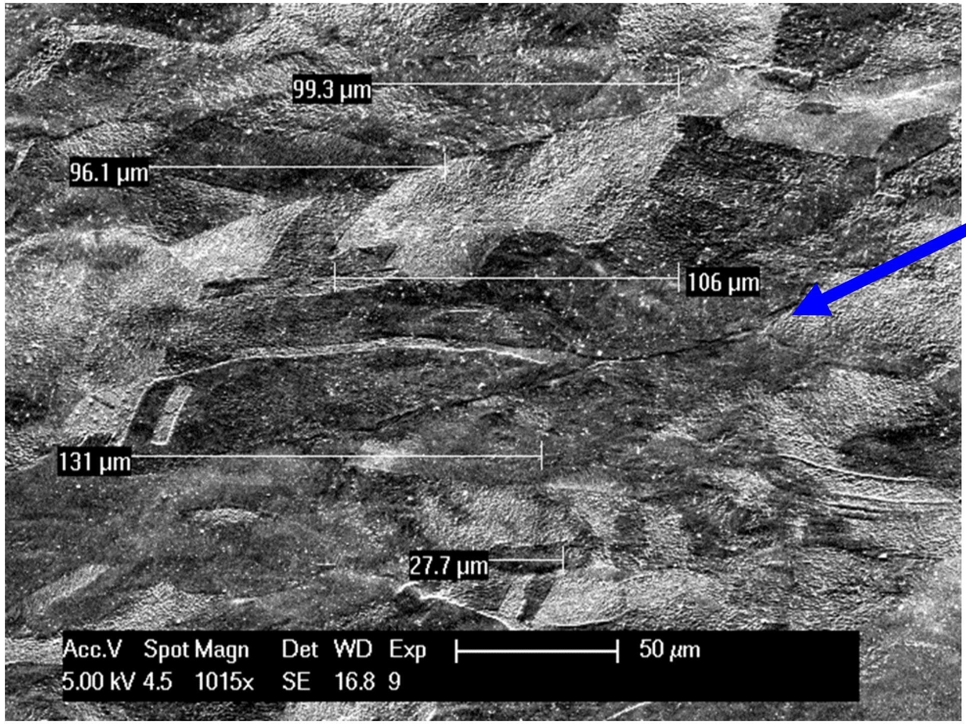


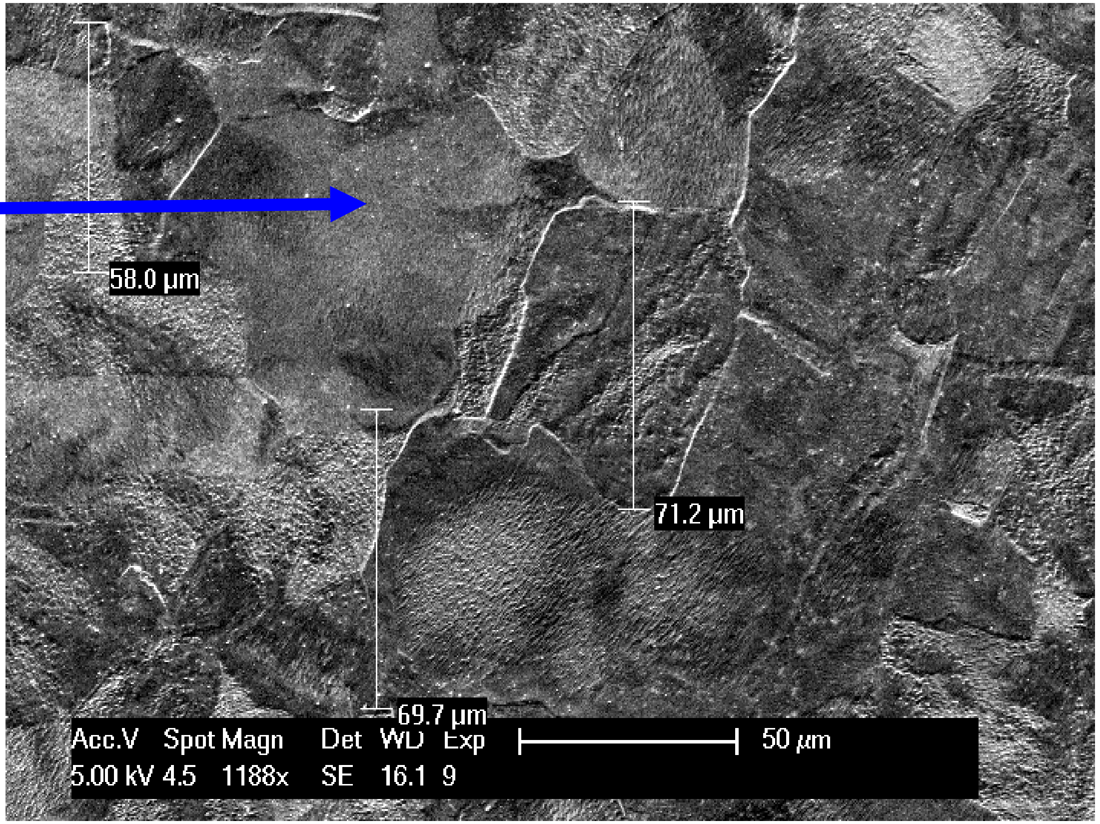
***Metallographic Etching Procedure:***

1) Standard **SUBU5** polishing
2) Passivation in 20 g/l Sulfamic acid
3) Ultrasound cleaning 5 min
4) 100 g/l $(NH_4)_2S_2O_8$ etching for 1 min
5) Ultrasound cleaning 5 min

# Grains Before Annealing (After Deep drawing)

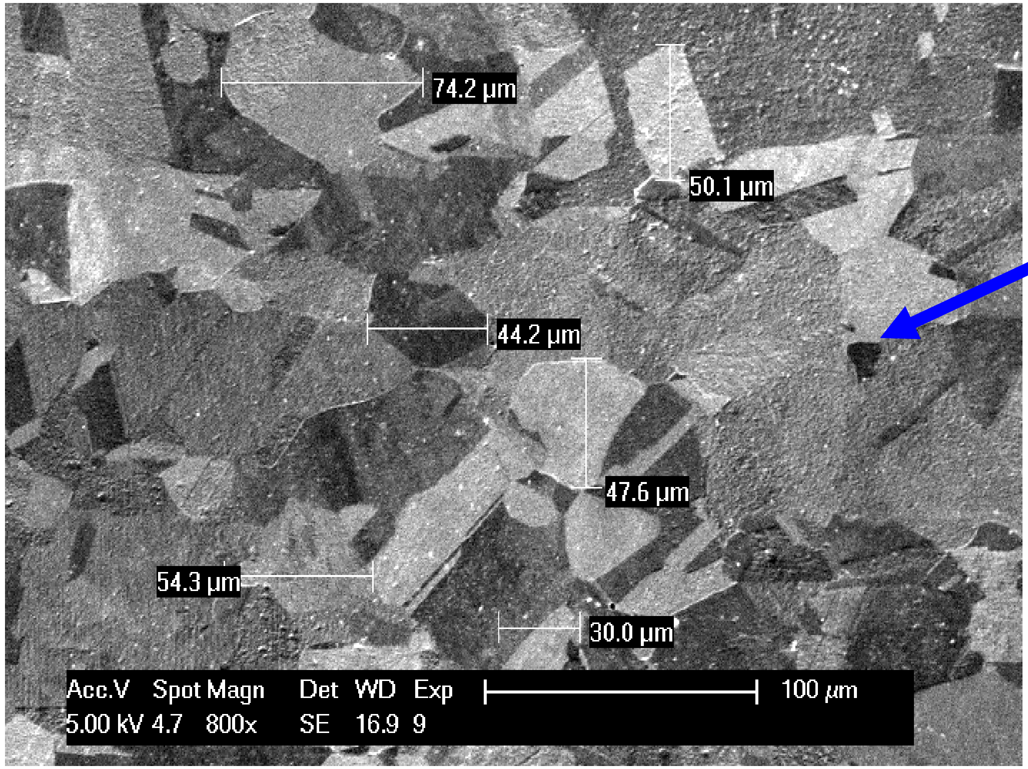
Grains Stretched

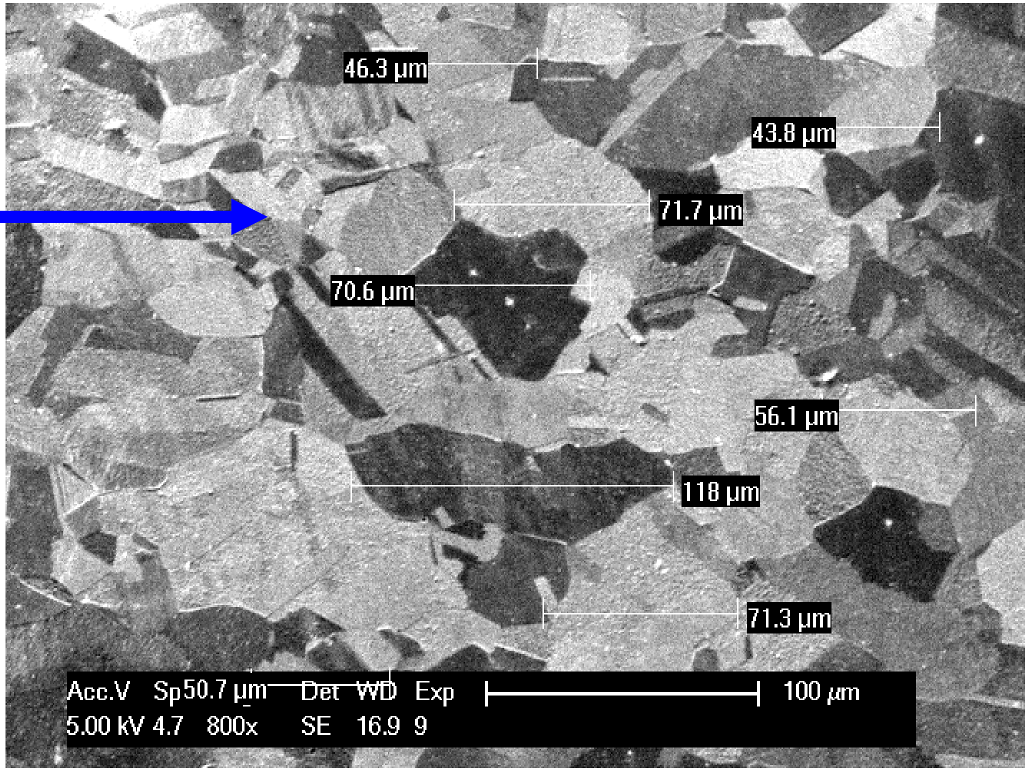


# Grains After Annealing

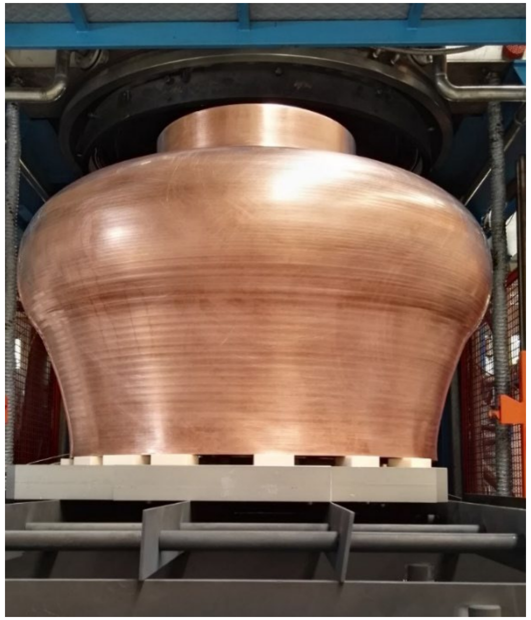
Grains not stretched



# STEP 4 Spinning of the intermediate conical die

NYLON CELL DIE +
NYLON CONE DIE

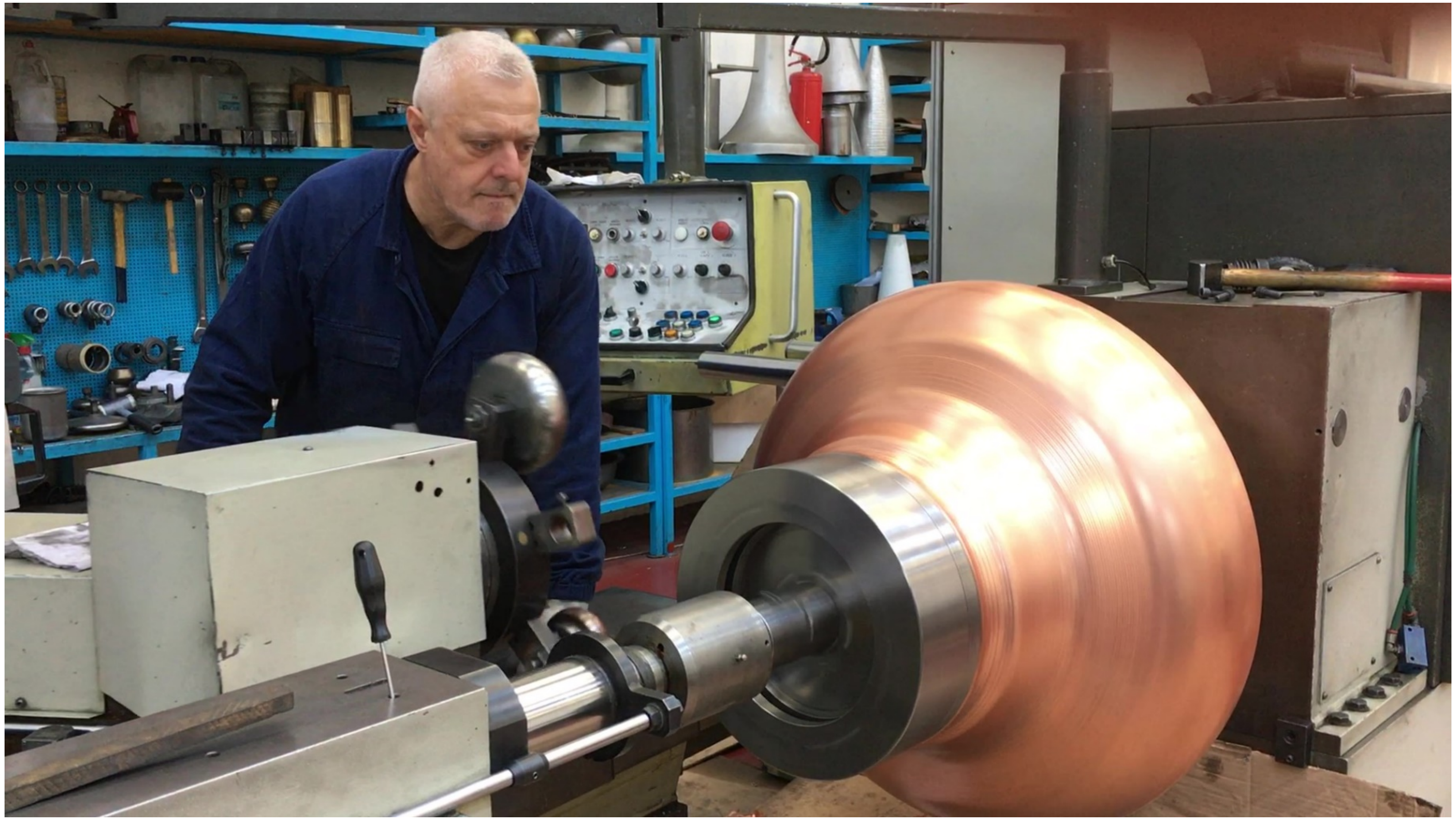


FIRST THERMAL ANNEALING

READY FOR THE SPINNING OF 2° HALF CELL

- **A thermal treatment is mandatory** for the spinning of the conical die

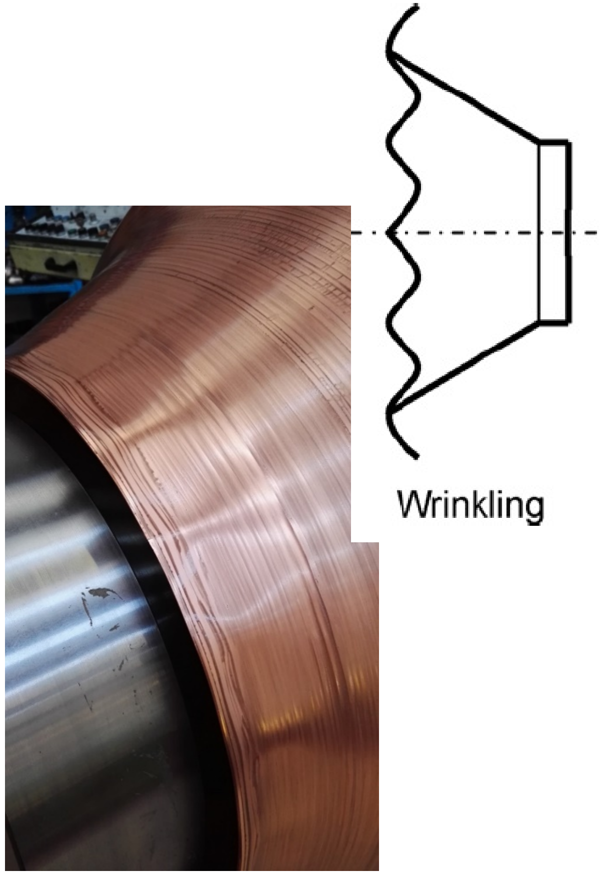
# STEP 5 Spinning of the 2nd half cell

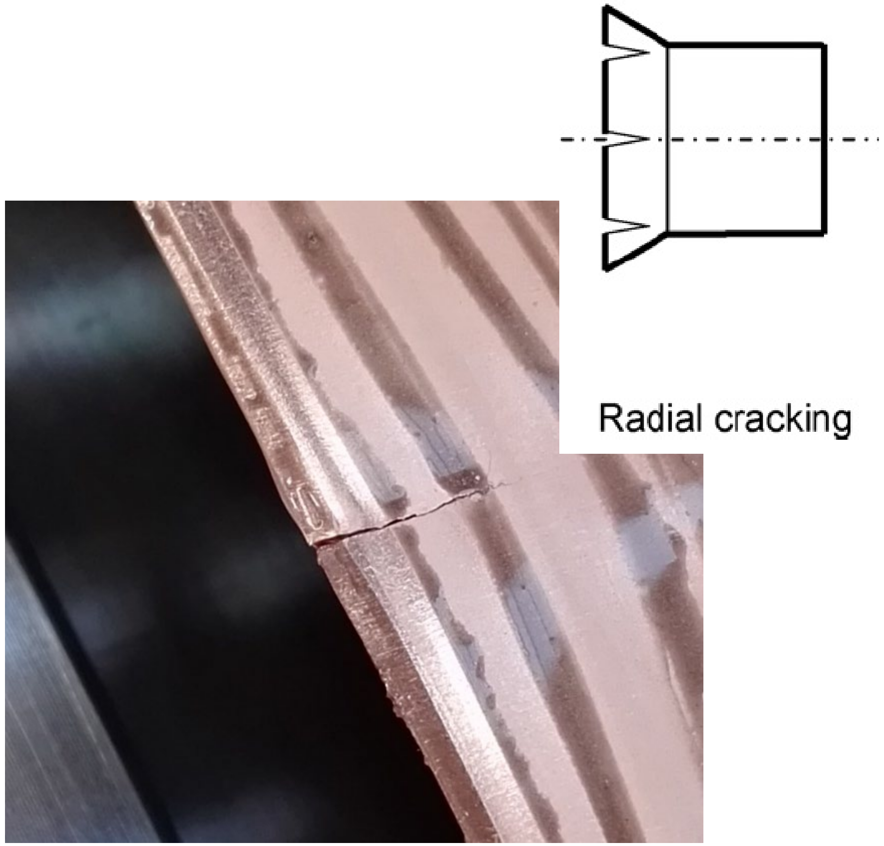


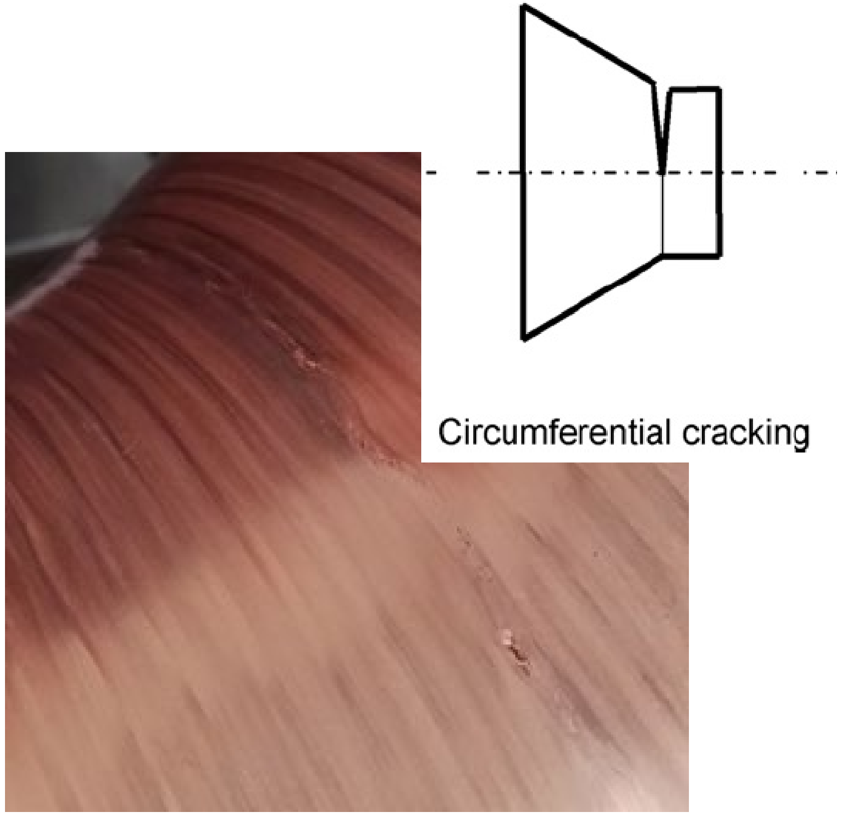
## Here comes the troubles

# Failure due to Copper Hardening

- The large amount of cold work introduced, produce copper hardening and consequent failures
- The sensibility of technician is fundamental to understand when the material need a thermal annealing



# Thermal annealings in Cavity #1

Ready for the 1st Thermal Annealing

Ready for the 2nd Thermal Annealing

# Thermal annealings in Cavity #1

1st Thermal Annealing

2nd Thermal Annealing

Cracks appear before the complete spinning of the second half cell

# Cavity #1


- Deep circunferential cracks on the iris

# Thermal annealings in Cavity #2

- The 2 annealings was anticipated and a third annealing was added

1st Thermal Annealing

2nd Thermal Annealing

1st Thermal Annealing

2nd Thermal Annealing

3rd Thermal Annealing

# Thermal annealings in Cavity #2

- The 2 annealings was anticipated and a third annealing was added

1st Thermal Annealing

2nd Thermal Annealing

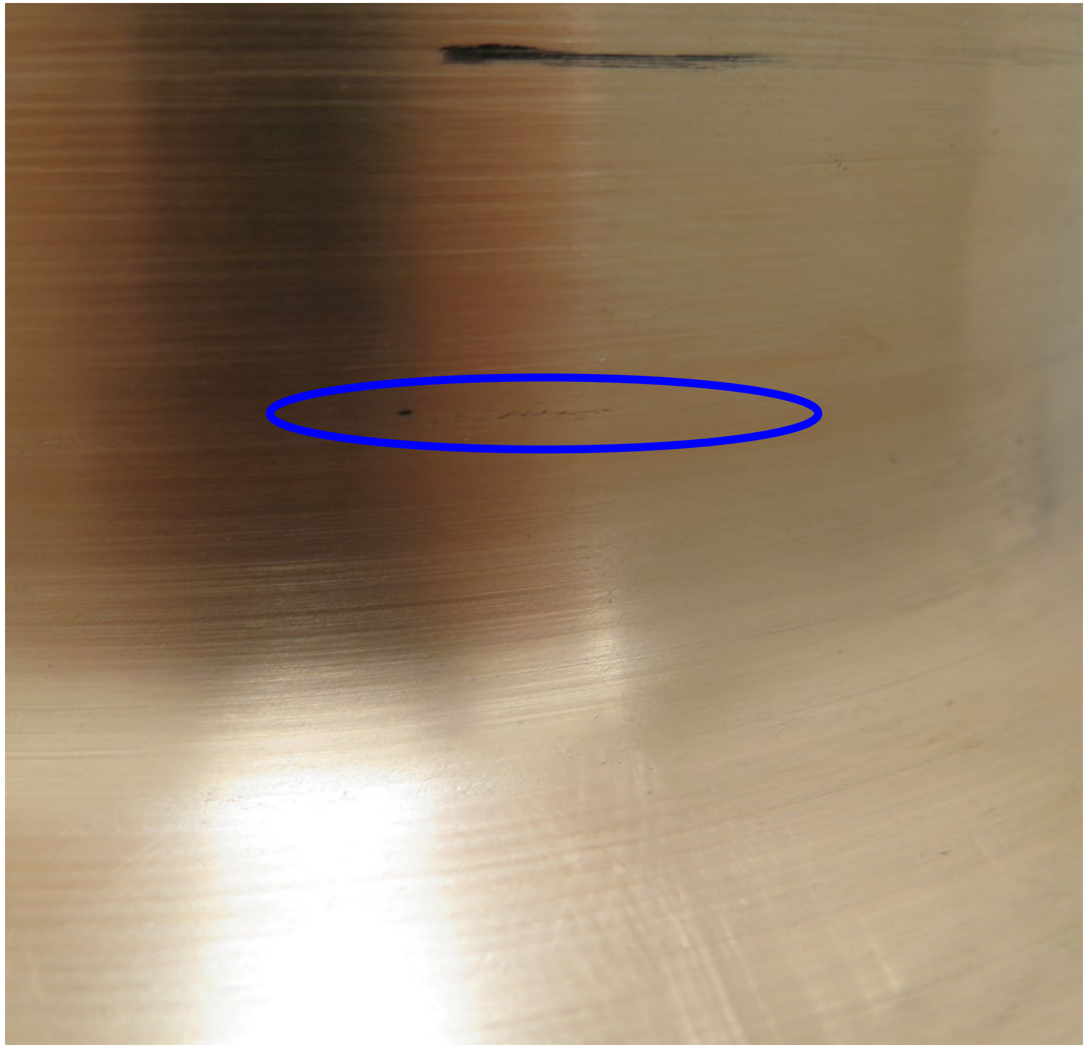
**Spinning of Cavity #2 completed**

1st Thermal Annealing

2nd Thermal Annealing

3rd Thermal Annealing

# Defects are still present also in Cavity #2



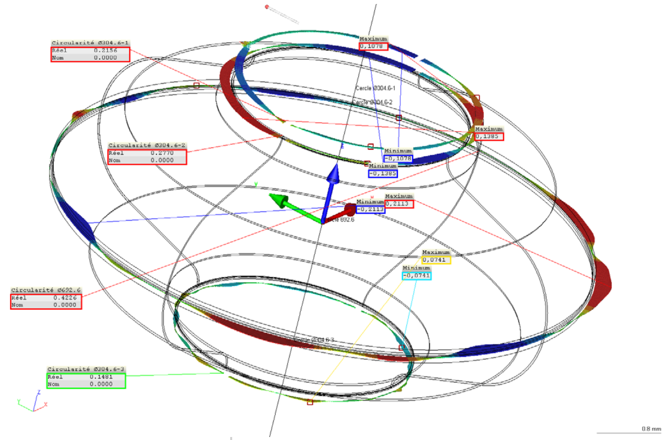
Small crack

# Internal surface

1st Half cell

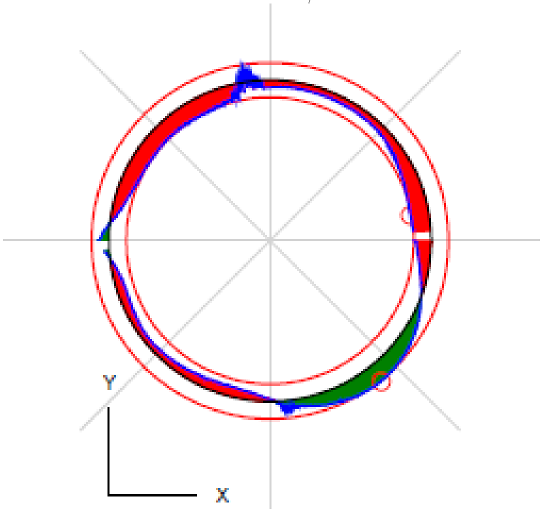

2nd Half cell

# Metrology of Cavity #2 (courtesy of Mikko Karppinen)

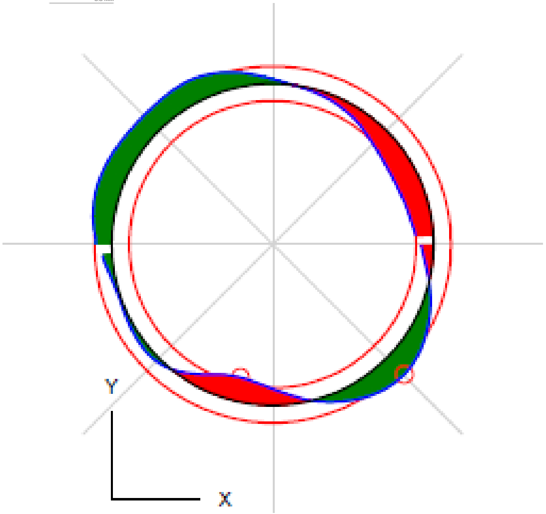


## Circularity

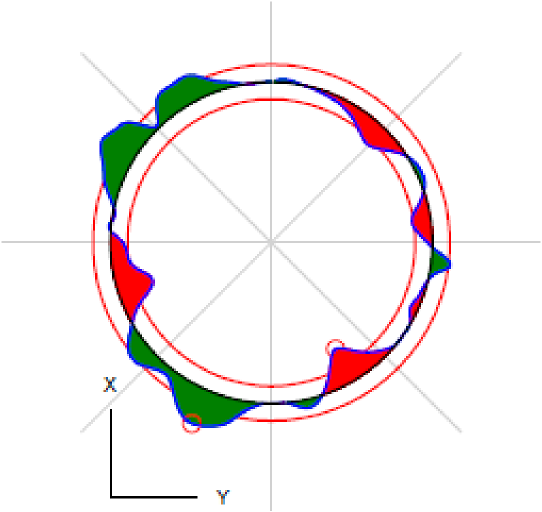
| No | Désignation | Val. réelle [mm] | Tolérance [mm] | Nombre Pts | Vitesse [mm/s] | Rayon Palp. [mm] | Type f. | L C | O/T |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Circularité Ø304.6-1 | 0,2156 | 0,2000 | 1965 | 40.00 | 4,9994 | | | |
| 2 | Circularité Ø304.6-2 | 0,2770 | 0,2000 | 1987 | 40.00 | 4,9994 | Spline | | 50 |
| 3 | Circularité Ø692.6 | 0,4226 | 0,2000 | 4507 | 40.00 | 5,0005 | Spline | | 50 |
| 4 | Circularité Ø304.6-3 | 0,1481 | 0,2000 | 1953 | 40.00 | 4,9994 | Spline | | 50 |



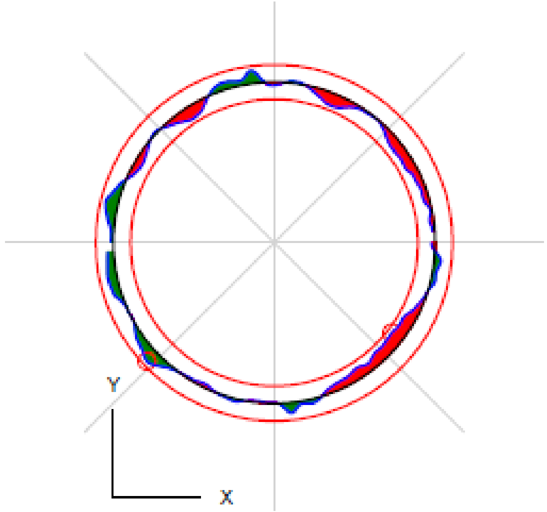

1: Circularity Ø304.6-1
Deviation: **0,2156 mm**




2: Circularity Ø304.6-2
Deviation: **0,2770 mm**



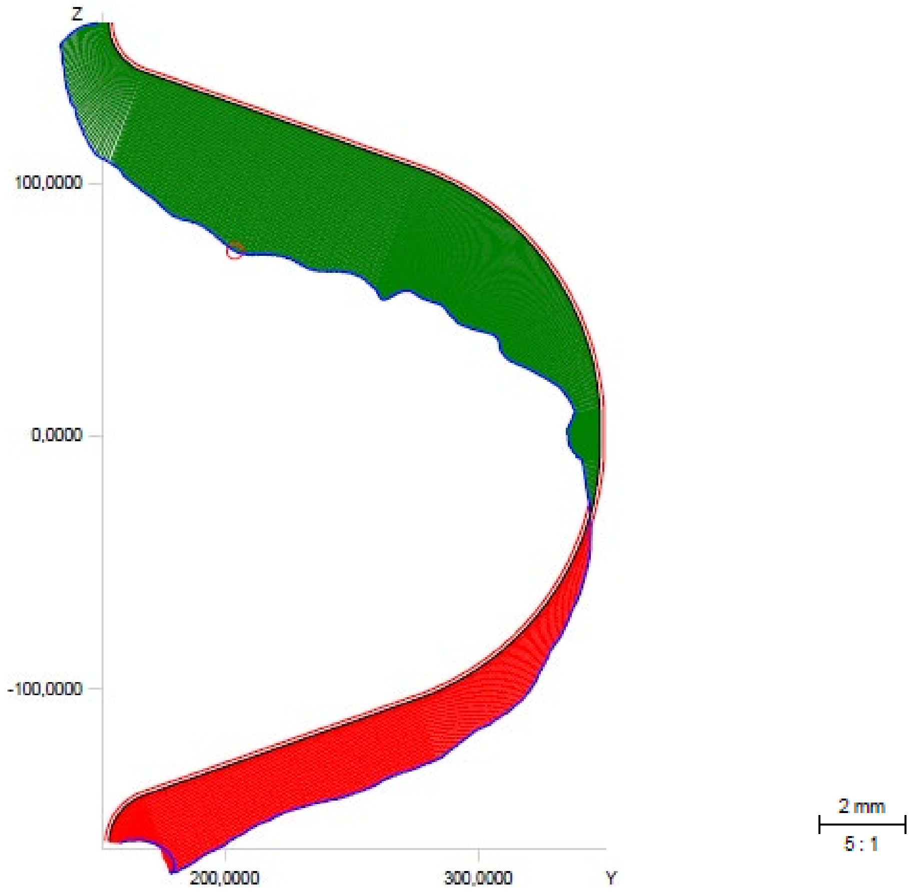

3: Circularity Ø692.6
Deviation: **0,4226 mm**




4: Circularity Ø304.6-3
Deviation: **0,1481 mm**

# Metrology of Cavity #2 (courtesy of Mikko Karppinen)

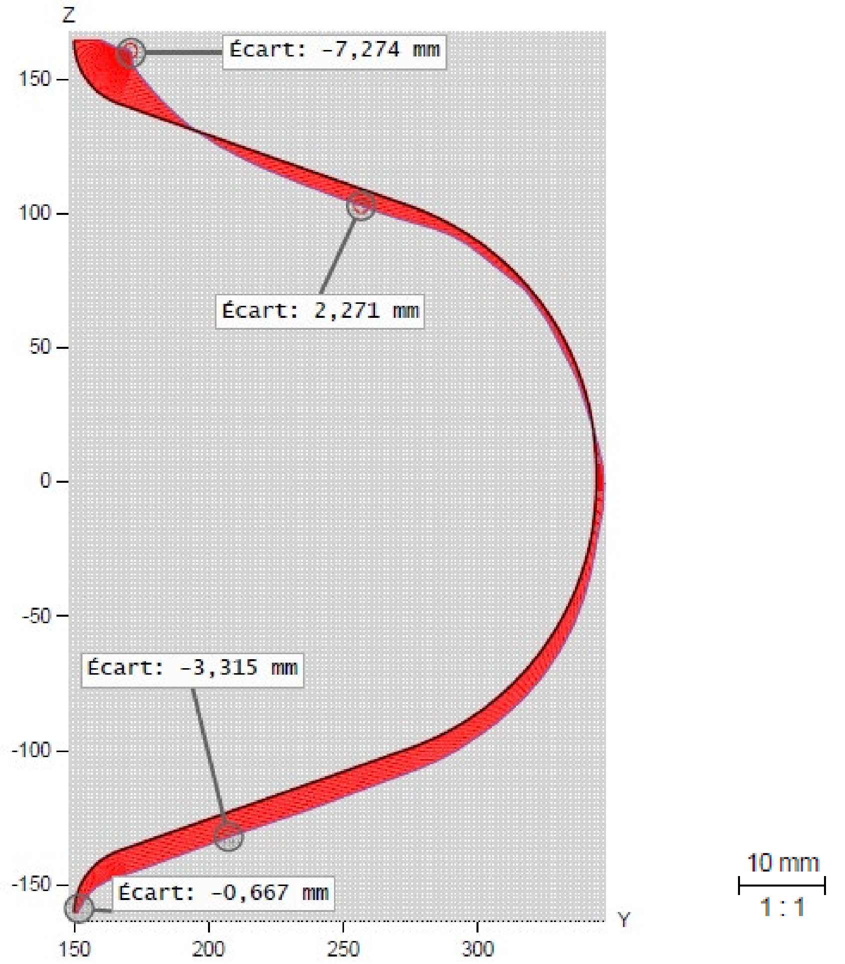
## Thickness




| No | Désignation | Nominal [mm] | Val. Min. [mm] | Pt. Min. | Val. Max. [mm] | Pt. Max. | Moyenne [mm] | Distance | Tol. Inf. [mm] | Tol. Sup. [mm] | Forme [mm] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Distance epaisseur moyenne | 2,4955 | 1,9154 | 970 | 4,4114 | 161 | 3,2014 | plan (normal nominal) moyen | -0,1000 | 0,1000 | 2,4959 |

# Metrology of Cavity #2 (courtesy of Mikko Karppinen)

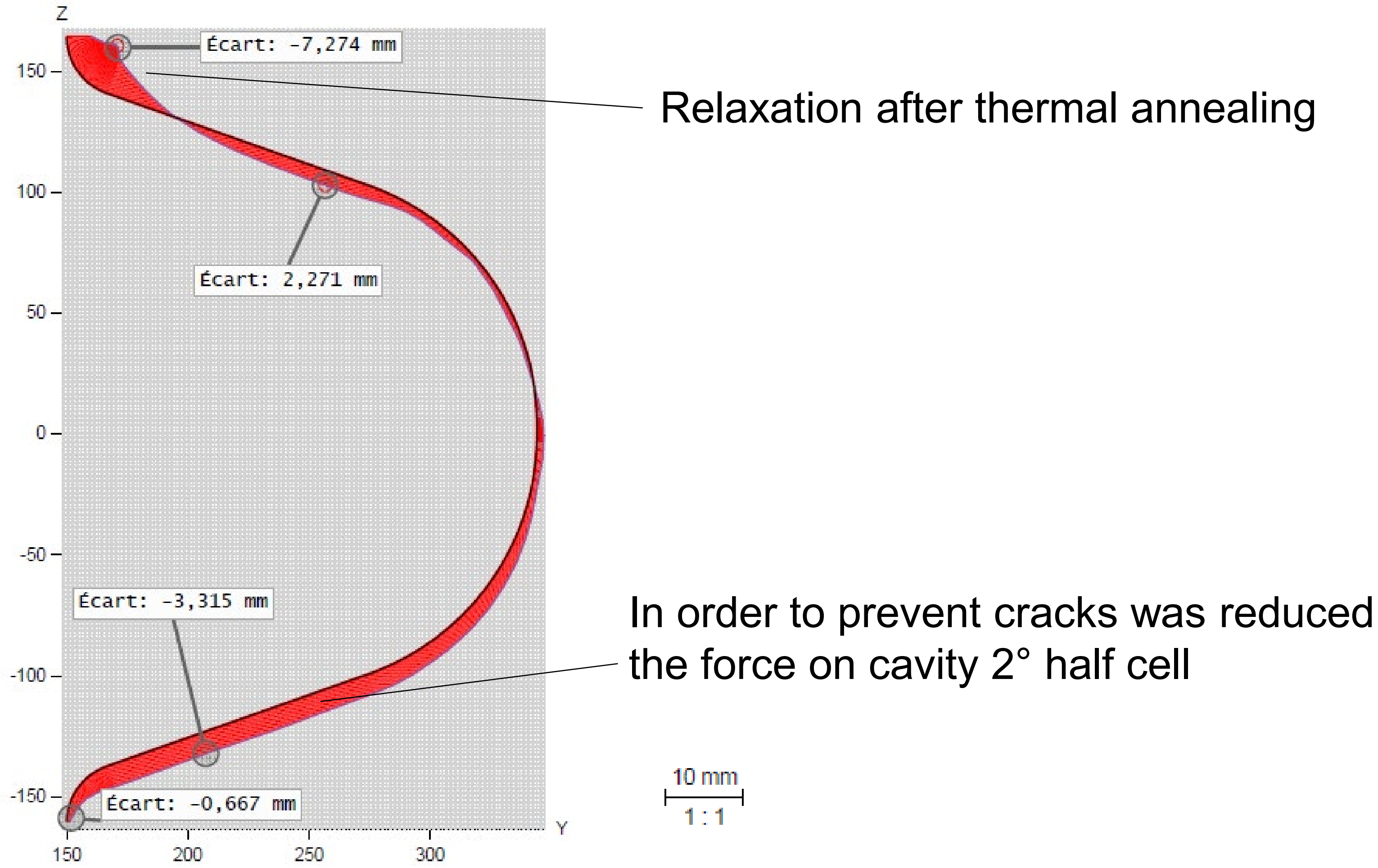
## Internal Profile




| | Nom | Valeur | Limite supérieure<br>Limite inférieure | Points | Type de filtre | Lc | Rayon palp... | Vmes[mm/sec] | Méthode d'évaluation |
|---|---|---|---|---|---|---|---|---|---|
| | Forme profil interieur | 14,7613 | 0,2000<br>0,0000 | 999 | | - | 2,5000 | 3,000 | Direction vecteur nominal |

# Metrology of Cavity #2 (courtesy of Mikko Karppinen)

## Internal Profile

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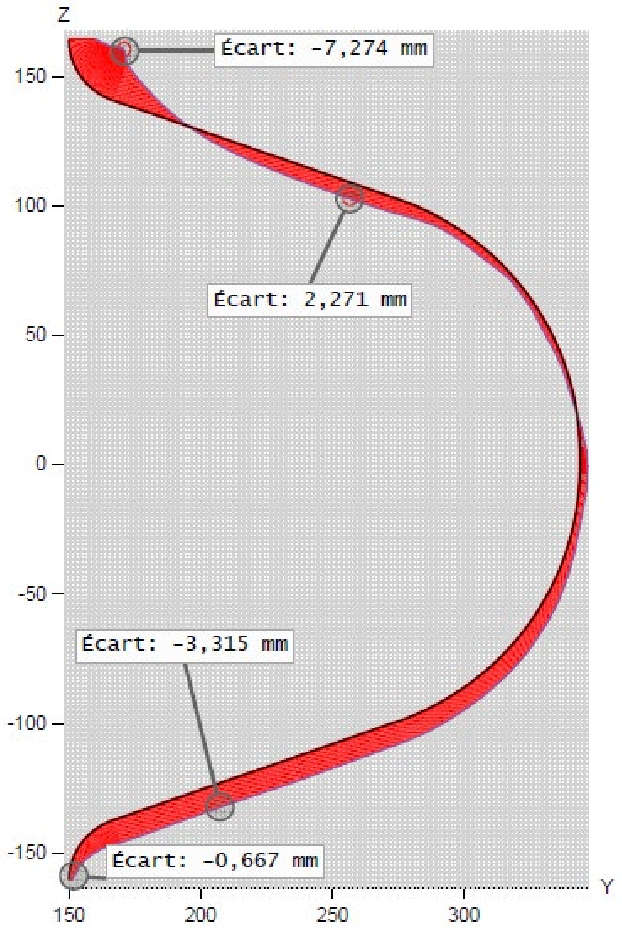
|---|---|---|---|---|---|---|---|---|---|
| | Forme profil interieur | 14,7613 | 0,2000<br>0,0000 | 999 | | - | 2,5000 | 3,000 | Direction vecteur nominal |

# Metrology of Cavity #2

## Internal Profile

Could be the zero point shifted?



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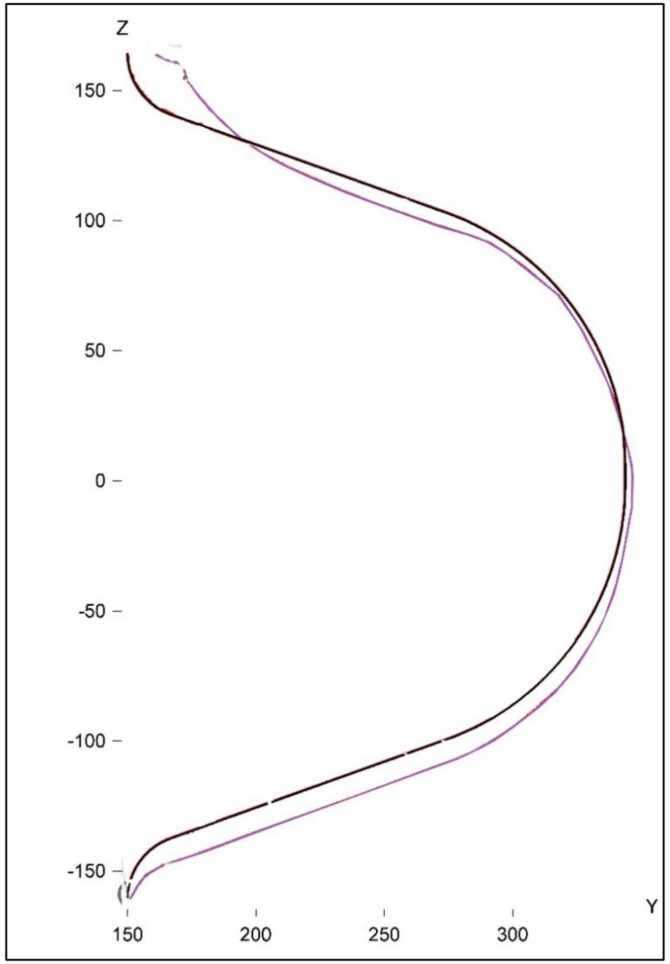

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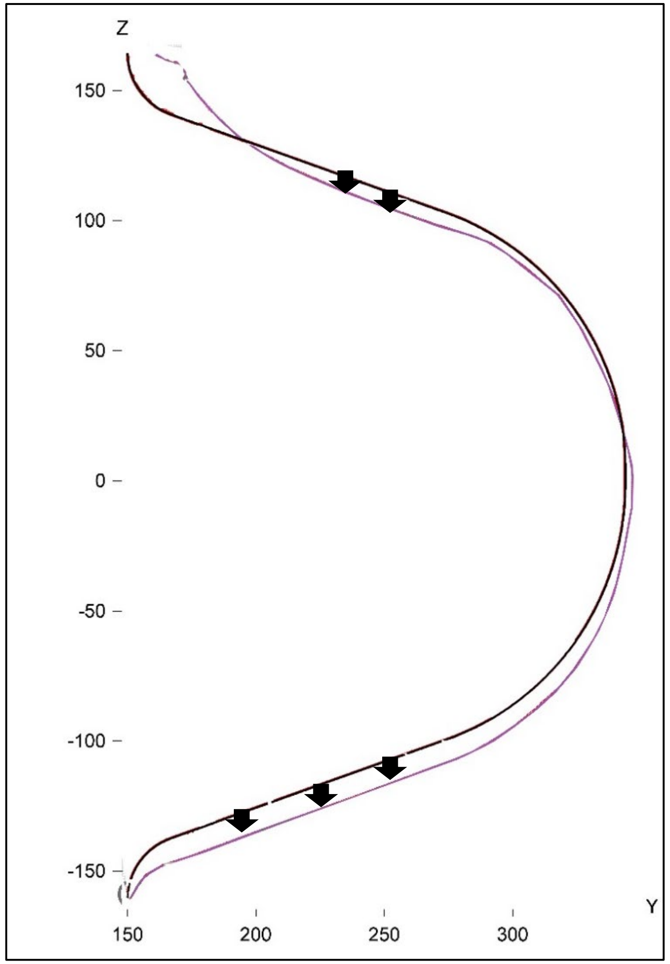
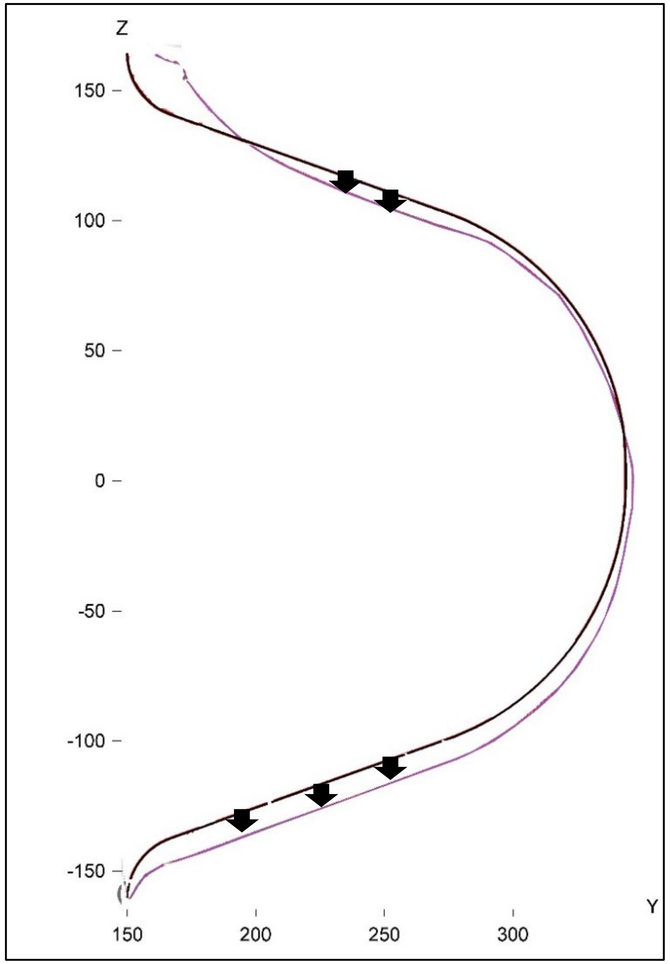
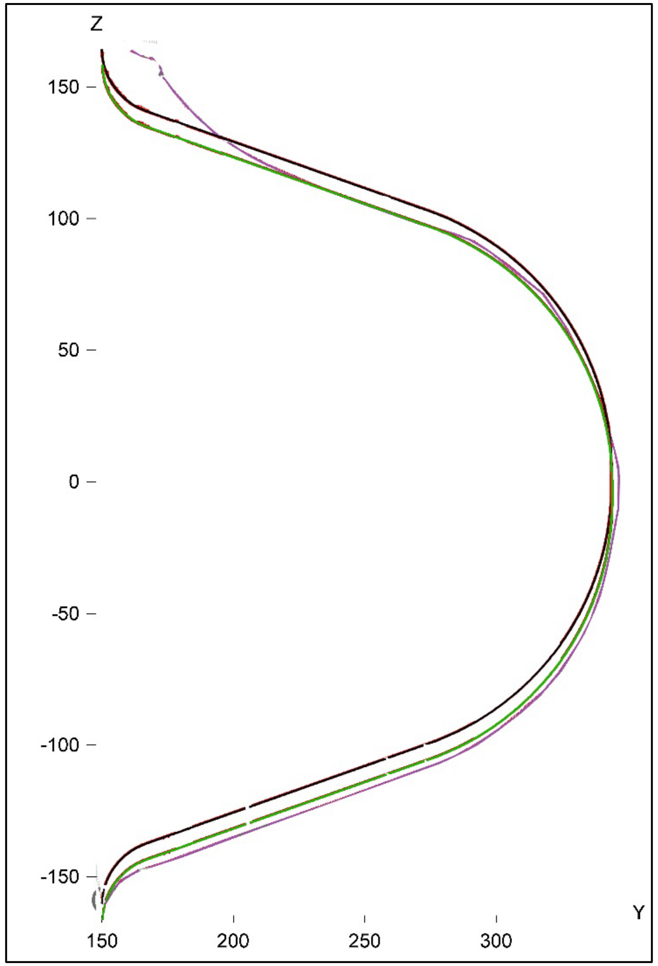


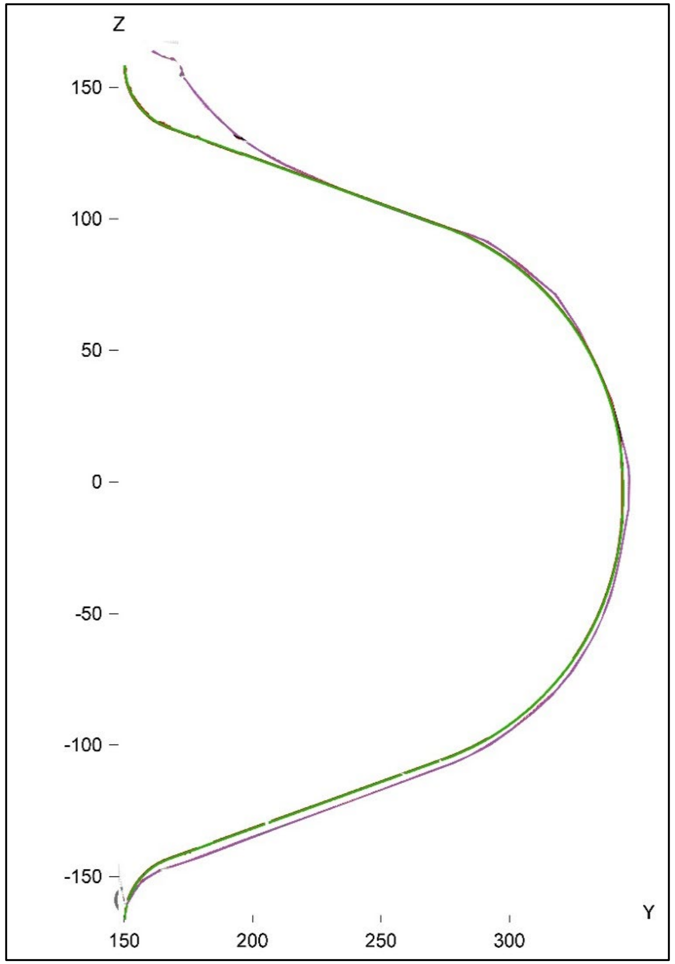
# Metrology of Cavity #2

## Internal Profile

Could be the zero point shifted?



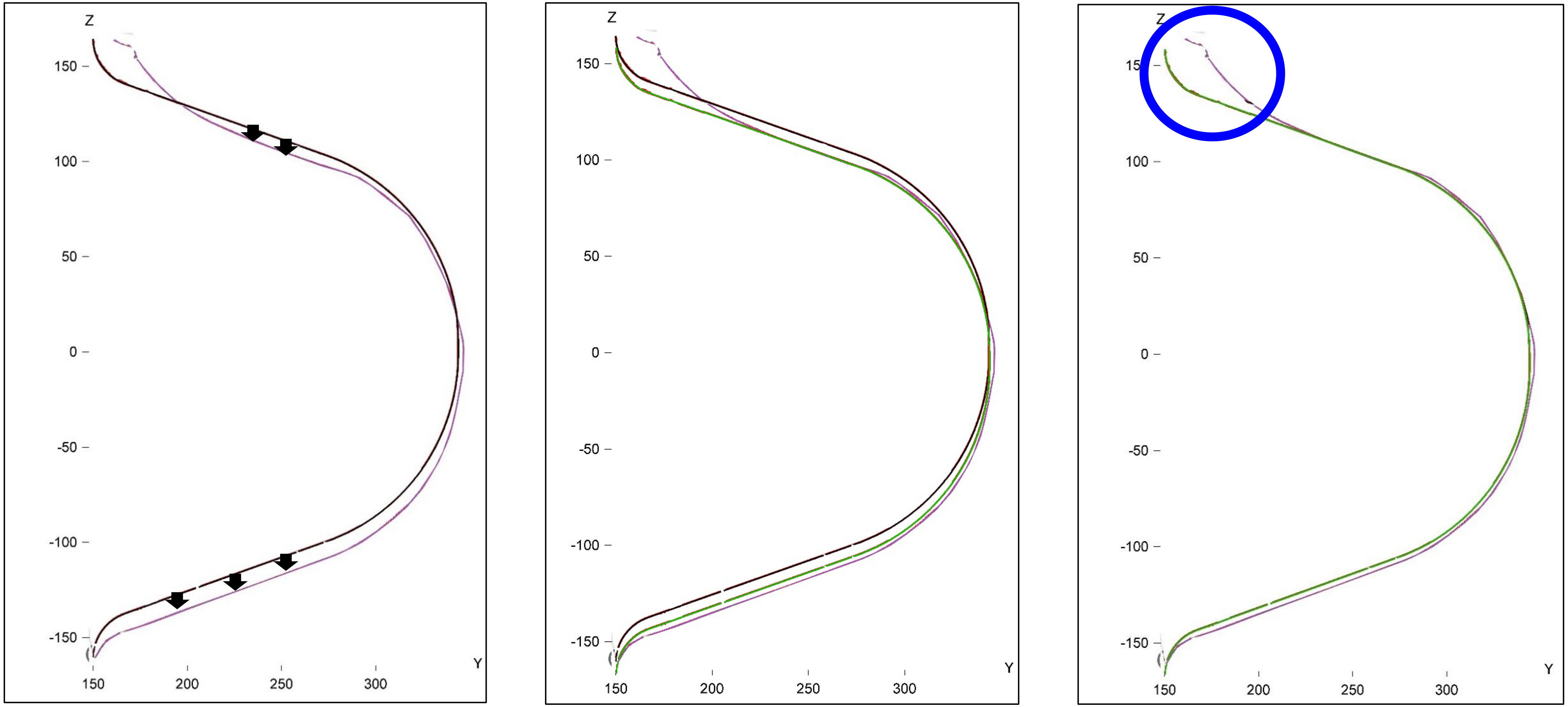



# Metrology of Cavity #2

## Internal Profile

Could be the zero point shifted?



# Conclusions and future work

- The feasibility to produce a 400 MHz seamless cavity is demonstrated
- Further developments are necessary to avoid cracks, increase geometry accuracy and internal surface quality (for example optimise annealing procedure and insert more intermediate die)
- In the next 6 months a systematic study on simulacra is planned to correlate spinnability to:
  - Thermal annealing conditions (temperature and time)
  - presence of intermediate dies (to reduce «vacuum spinning» and consequently wrinkling)

# Ideas for an industrialization of the process

- Increase the riproducibility using a CNC lathe instead of a semi-authomatic one
- Evaluate the possibility to apply a finite element simulation in order foresee the spinnability of elliptical cavities with different frequency supporting the process rescaling
- Evaluate the possibility to spun cavities starting from an extruded copper tube instead of copper plate in order to have a symmetrical amount of cold work applied

# Thank you for your attention