Thin Polished Glass Monolithic & Segmented Mirror Development

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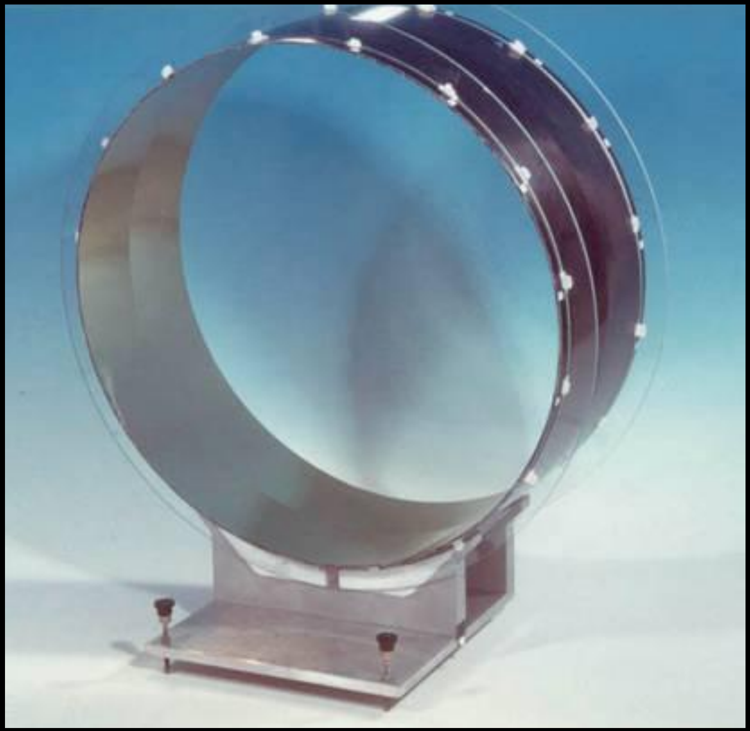
From State of the art to … lightweight concept?

1999, CHANDRA telescope
Super-polished Zerodur mirror shells:
THICK (35mm) and FEW (4)
Area = 1100cm^2
MaxDiam = 120cm
HEW = 0.5"

“High resolution” optics @INAF-OAB



SiC monolithic shell,
Replica process
Ghigo et al. (1999)

Fused silica monolithic shell,
Direct polishing
Civitani et al. (2012)

Development program founded by ASI (Italian Space Agency)

Proposal approved by ASI (first ranked, after peer review by external referees) in the context of the last Call on new Technologies. KOM meeting March 2016 (INAF/Brera + POLIMI)

TWO TASKS:

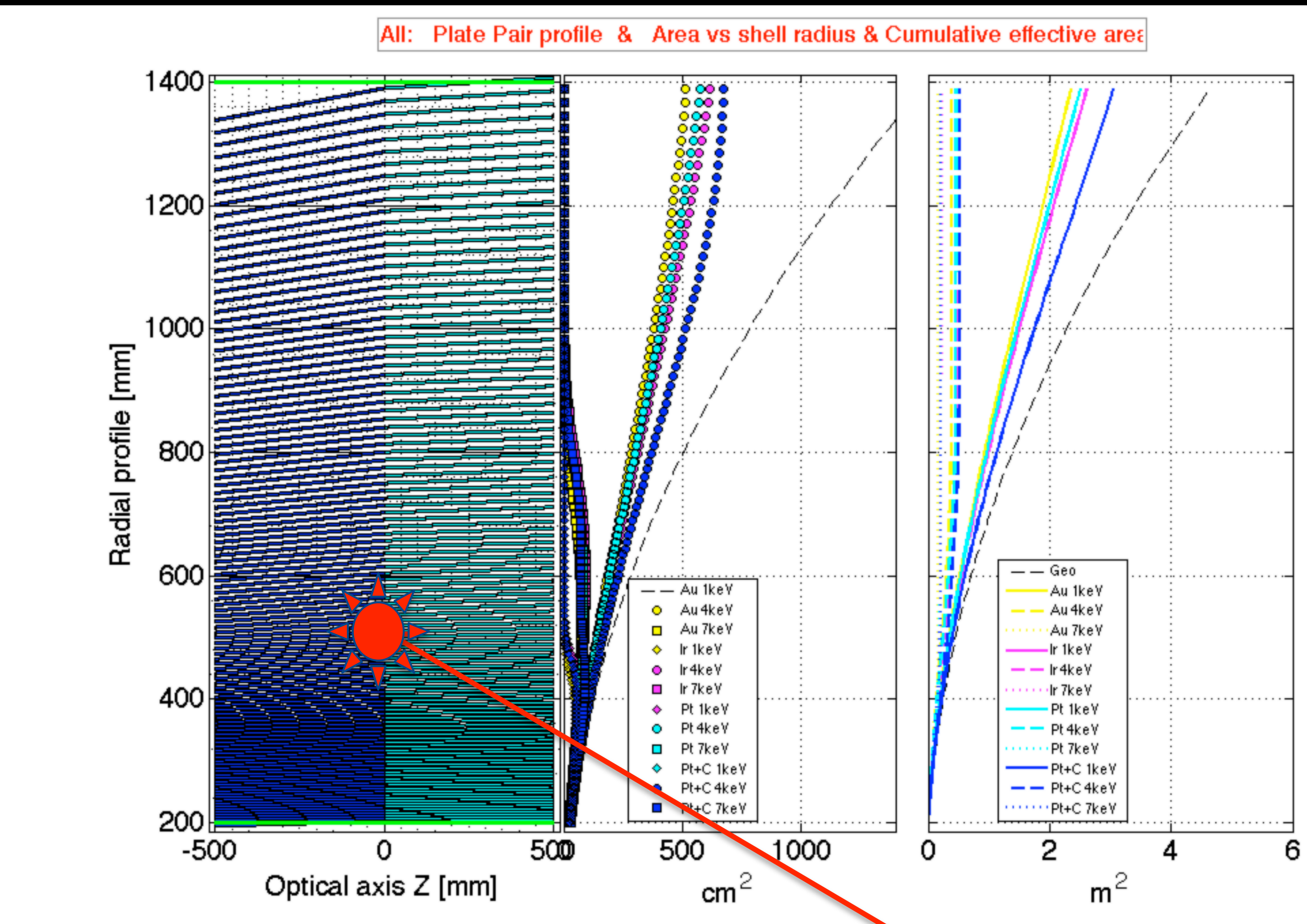
- development of high throughput X-ray optics based on "cold" slumping of thin glass foils (M. Civitani et al. 2015, Basso et al. 2016)

- **DEVELOPMENT OF HIGH PRESION OPTICS FOR "BEYOND CHANDRA" programs → X-Ray Surveyor**

Presentation summary

- Shell design
- Tolerance analysis
- Material selection
- Process overview
- Development status & preliminary results

Full optic



Focal Lenght = 10m
Shell Lenght = 500+500 mm
Thickness range = 2-4mm
Wolter-I design

→ Around 110 shells

(see next presentation for structural considerations)

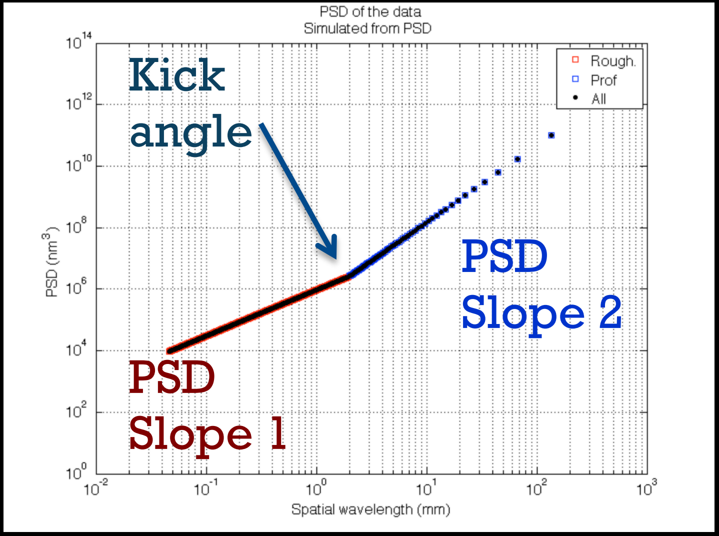
Shell under development

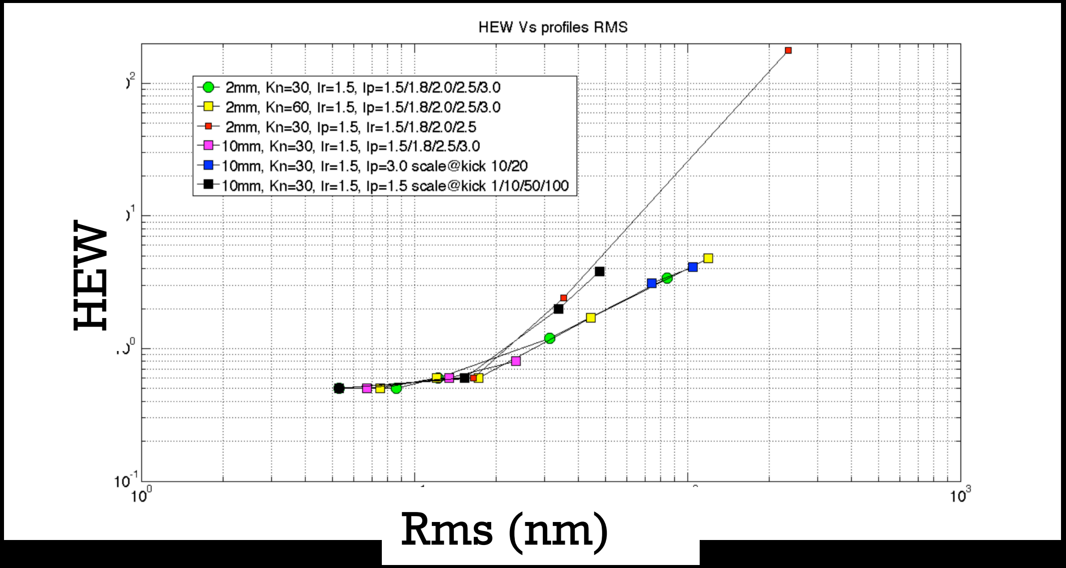
Prototypal shell manufacturing program

Realized Prototype Shell#7	**New Prototype Shell#4**
5000mm	5000mm
487mm	487mm
2mm	2mm
200mm	270mm
Polynomial	Wolter
1.369kg	1.8kg
10’’ (5’’ goal)	2’’ (1’’goal)

Tolerances analysis

- Conical error can be compensated during integration, 10'' compatible.
- For out of roundness, HEW depends on the in-phase/out-of-phase configuration, less than 400nm PtV to be sure.
- The first order curvature amplitude less than 100nm.
- Figure errors with rms around 15nm rsm are compatible.
- Surface micro-roughness below 0.5nm rms.



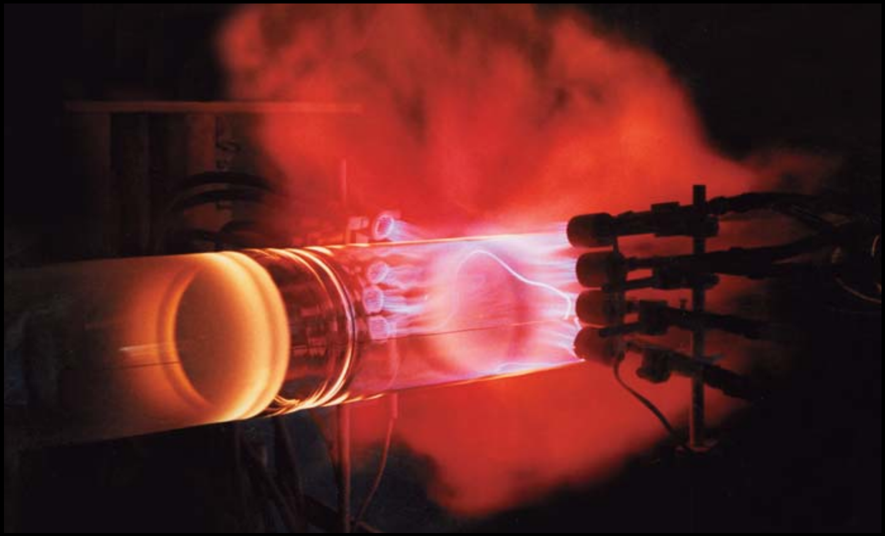


Materials: Fused silica

	Glass 263	Eagle Glass	Silicon	Fused Silica
Density (g/cm^3)	2.51	2.38	2.33	2.2
Thermal Conductivity ($W\ m^{-1}\ K^{-1}$)	0.8	1.09	148	1.37
CTE ($10^{-6}\ K^{-1}$) at 300 K	6.3	3.17	2.6	0.58
Young Modulus (GPa)	72	73.6	150	73

- Low thermal expansion
- Excellent material for figuring, polishing and ion-beam correction (completely amorphous!)
- Space compliant (SiO2 also used for Einstein shells)
- Available on large size formats
- Low stress
- Possible "near net shaping" before polishing

Raw shell procurement



Heraeus Quarzglas (Germany)

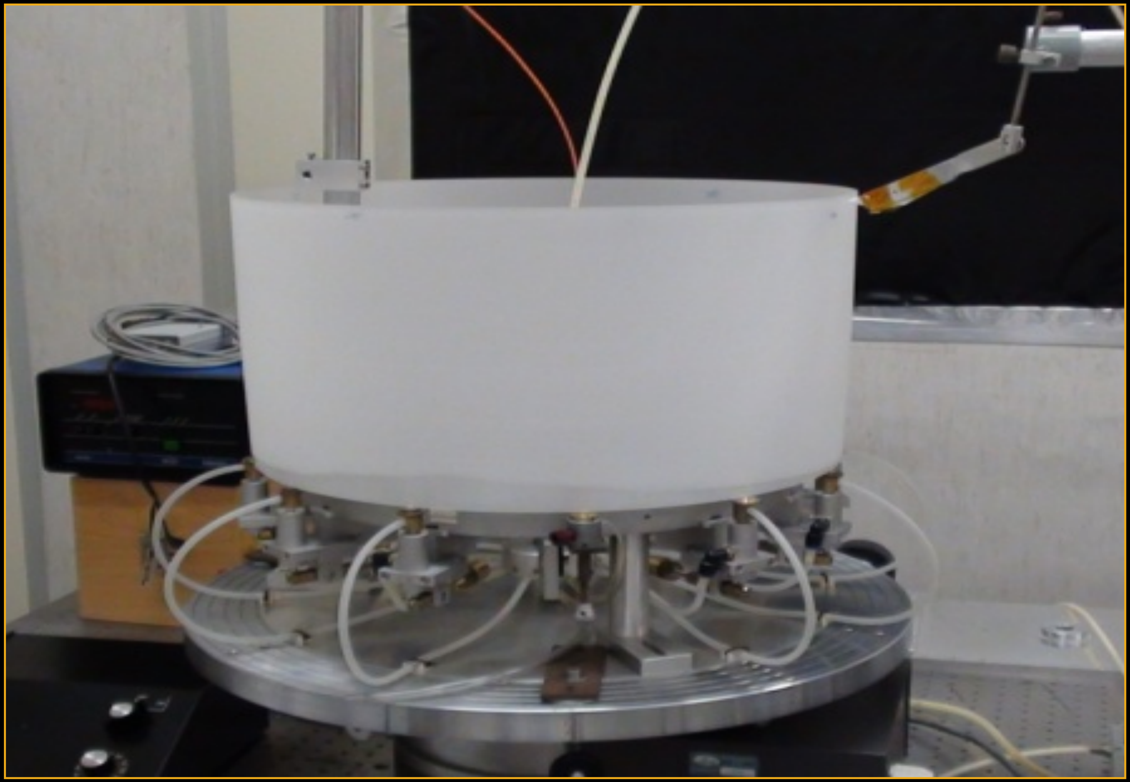
NOW

- Raw material: high purity Quartz (HSQ300)
- Tube diameters: 2 – 1000 mm
- Wall thickness: 0.5 – 13 mm
- Close to the double conical shape with raw grinding.

NEXT:

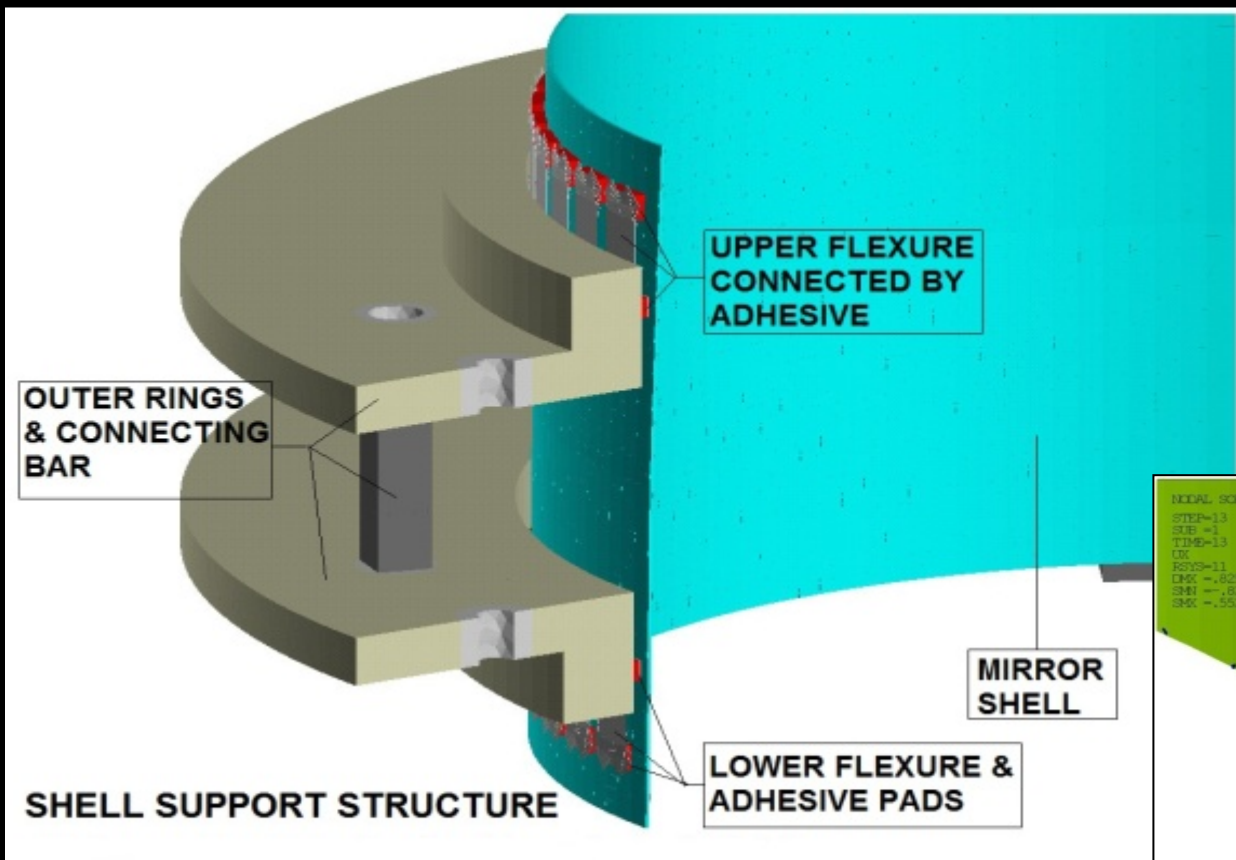
- Close to the double conical shape with hot-slumping!!!
- Bigger tubes are techonologically possible

Starting point: Raw grinded fused silica shells (from HERAEUS)

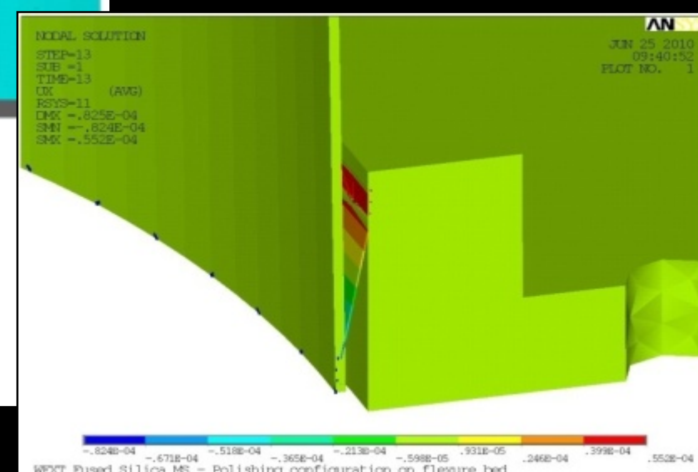


- Rough surface after raw grinding: around 0.7-1.2 micron rms.
- OOR (on astatic support) errors depends on the shell: typical range is 5-50microns

How to handle a thin & short glass shell: the Shell Supporting System



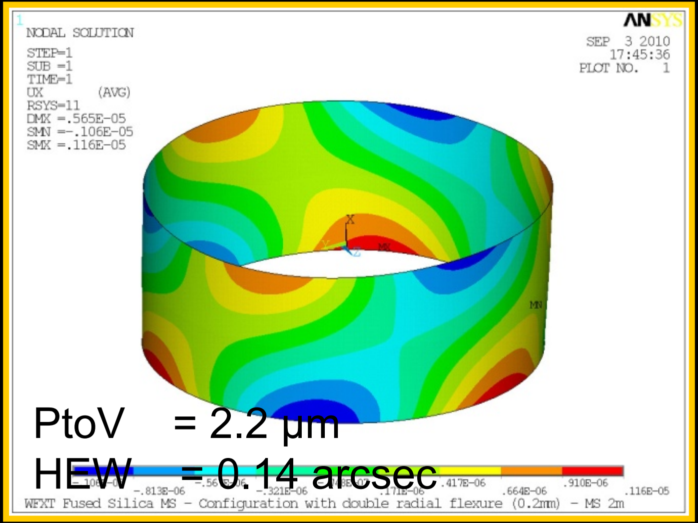
- -Temperature effects
- - Gravity effects
- -Integration errors



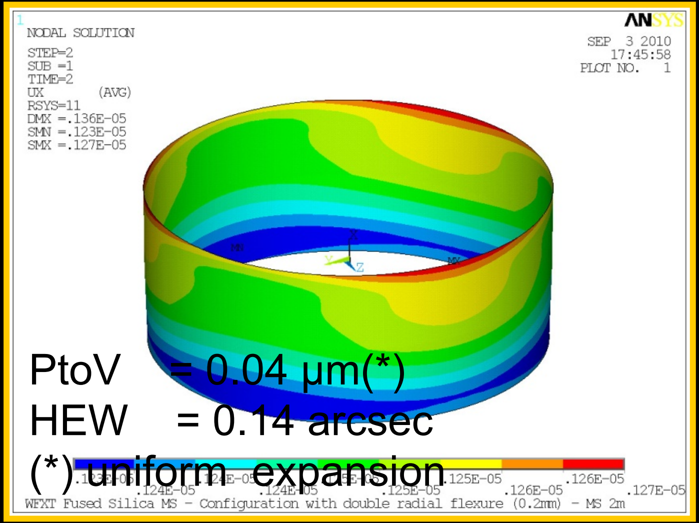
Shell Support System (SSS)

Gravity & thermal effects

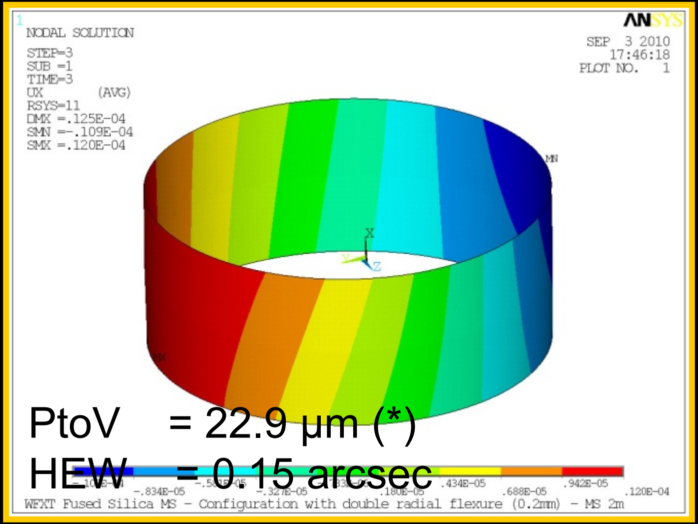
Axial gravity



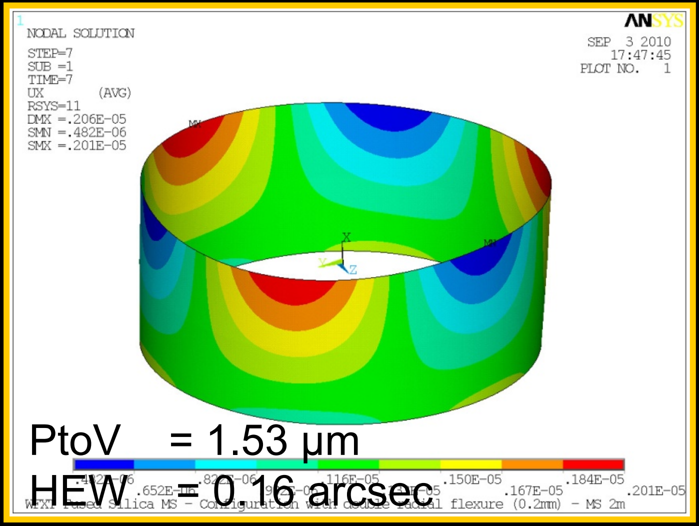
ΔT = +10°C (machining heating)



Lateral gravity



ΔT = +1°C on whole assembly



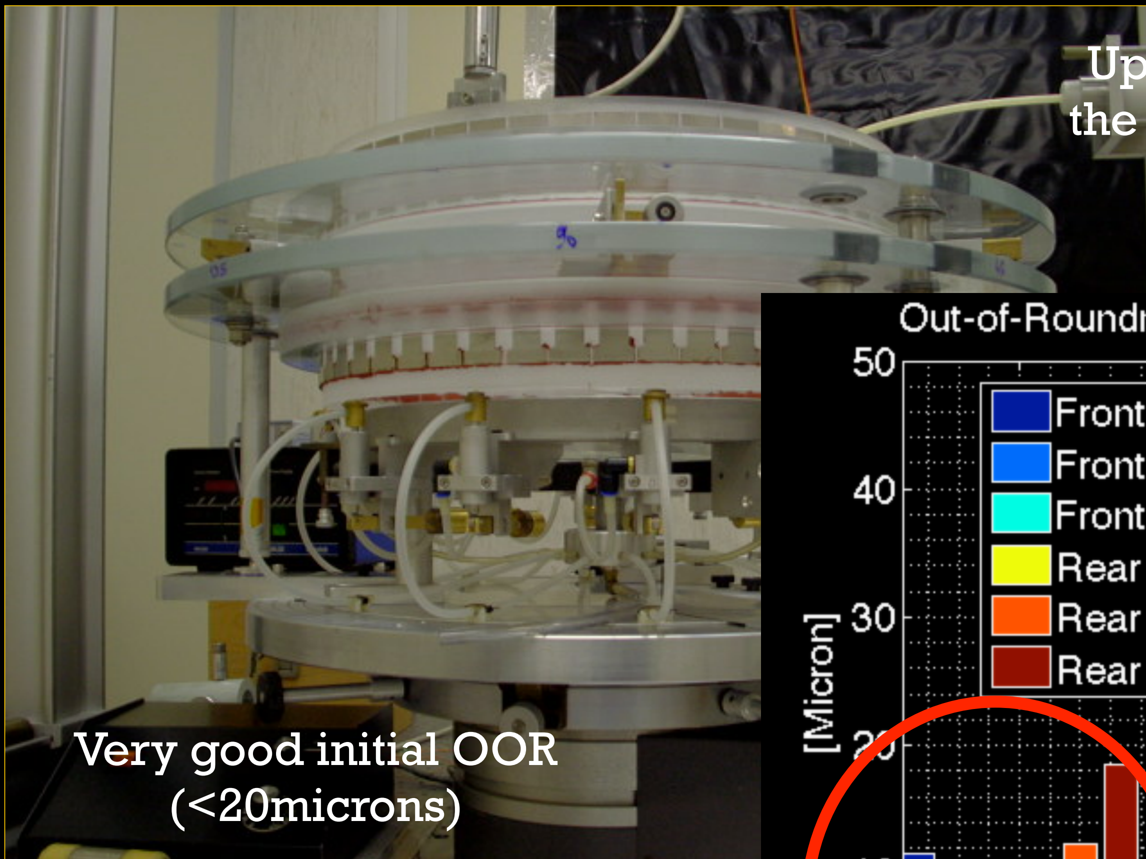
Credits BCV

An almost complete manufacturing-integration sequence (FEA)

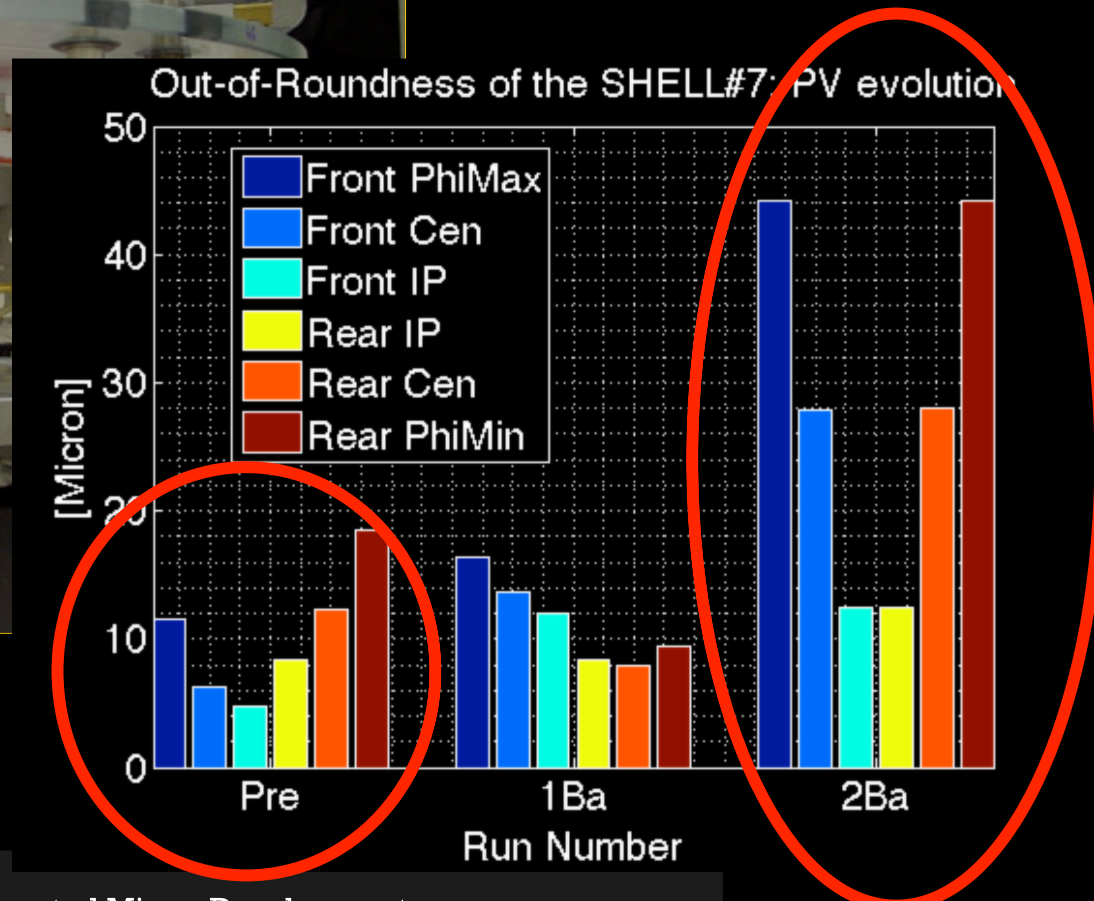
Contribution to the error budget	HEW Worst case [arcsec]	HEW Best case [arcsec]
Axial gravity release + shrigake + DT (100Micron) + SSS interface tolerances	0.56	0.56
Axial gravity release + shrinkage + DT (100Micron) + SSS interface + Lateral gravity (= test on ground)	0.92	0.69

Integration of shell#7 into the SSS @INAF/OAB

Up-grade of the process to limit the deformations introduced with the operations



Very good initial OOR (<20microns)

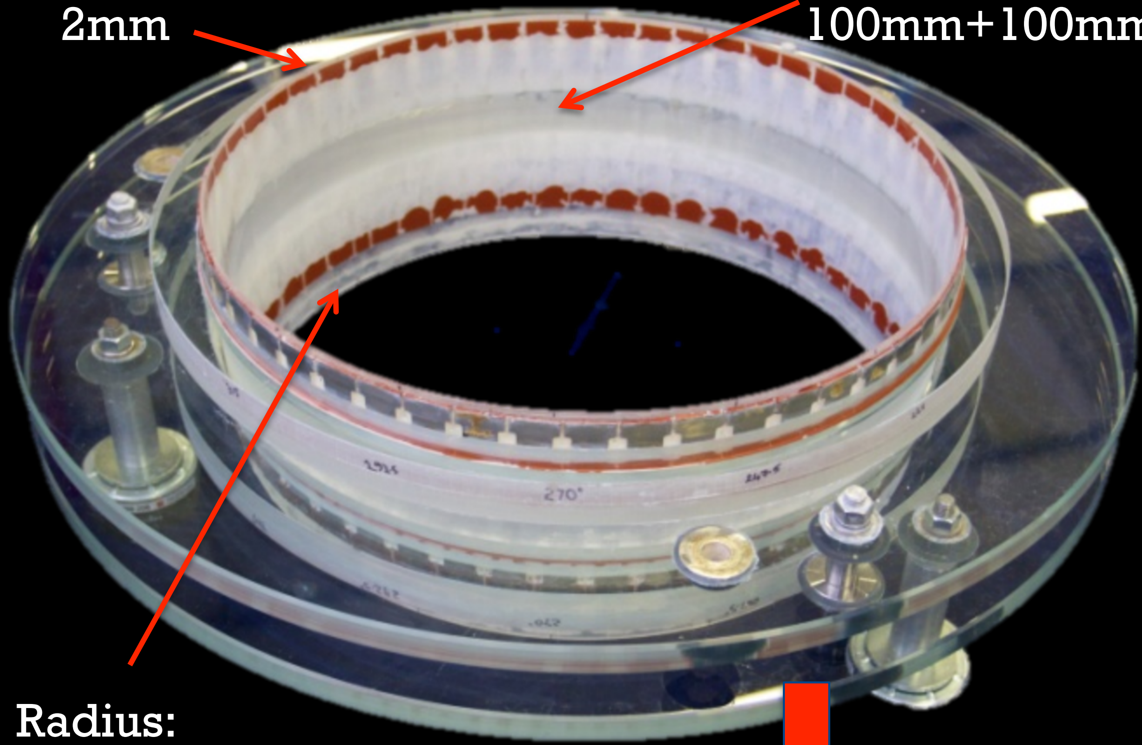


Thin shell integrated in the SSS

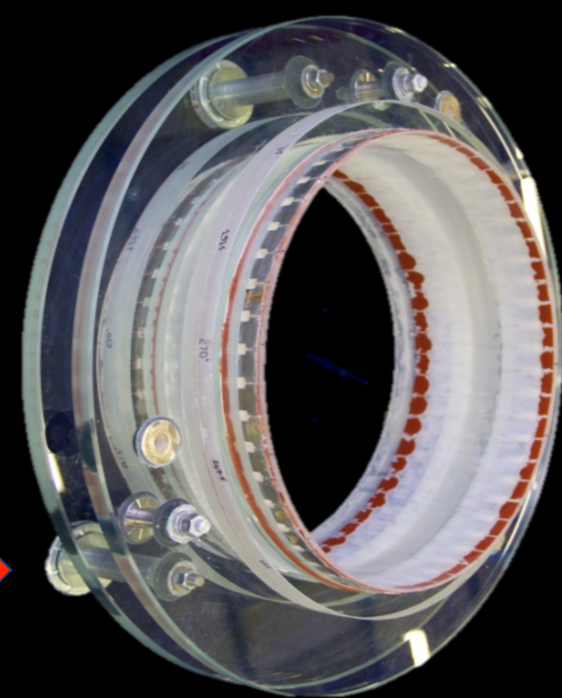
Thickness:
2mm

Length:
100mm+100mm

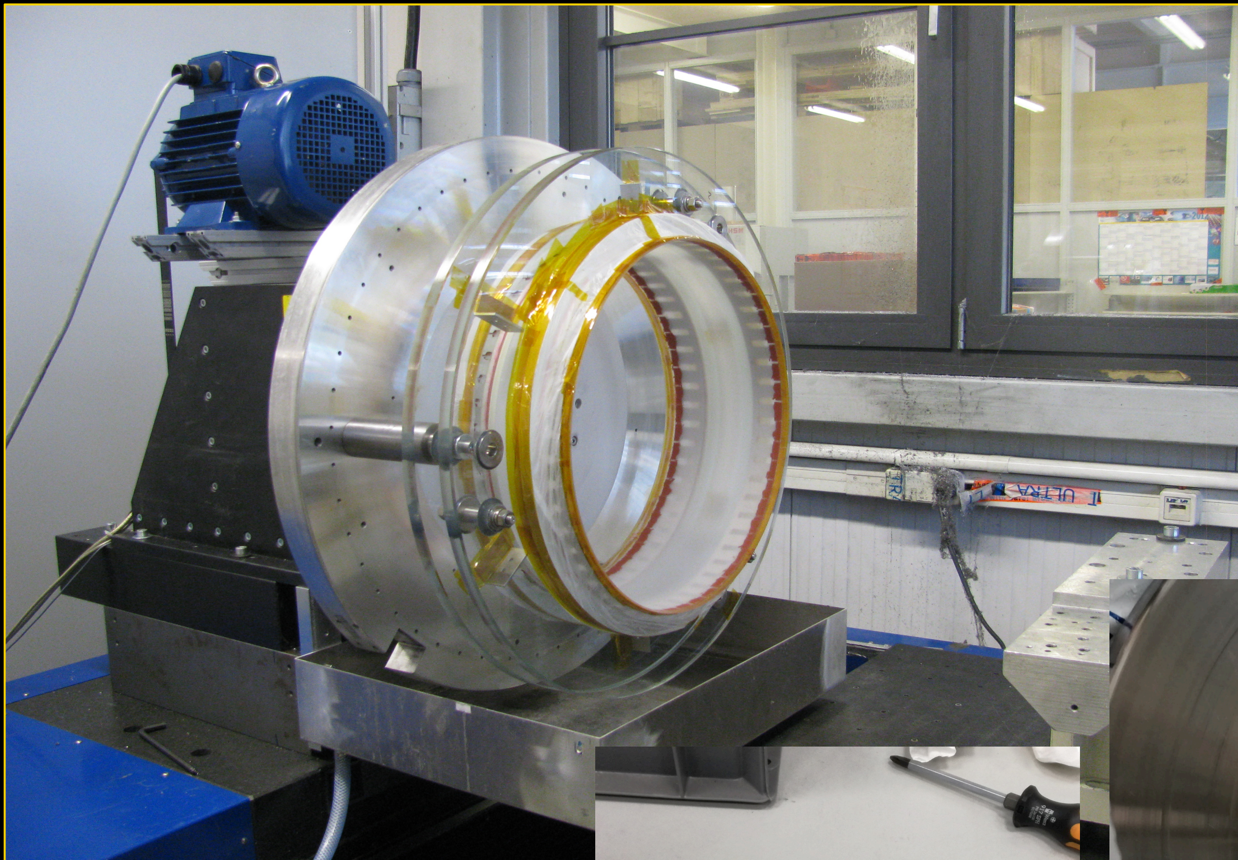
Machining/
metrology/
calibration
Can be managed in
horizontal position



Radius:
243.25 mm

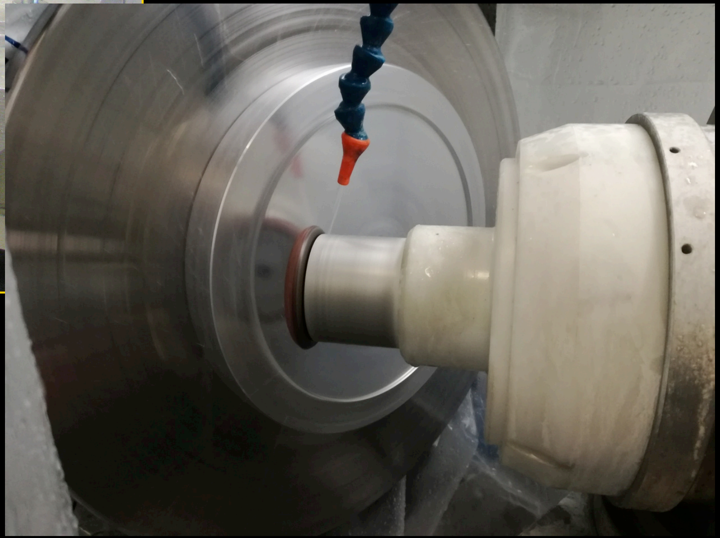


Fine grinding [@LT-Ultra]



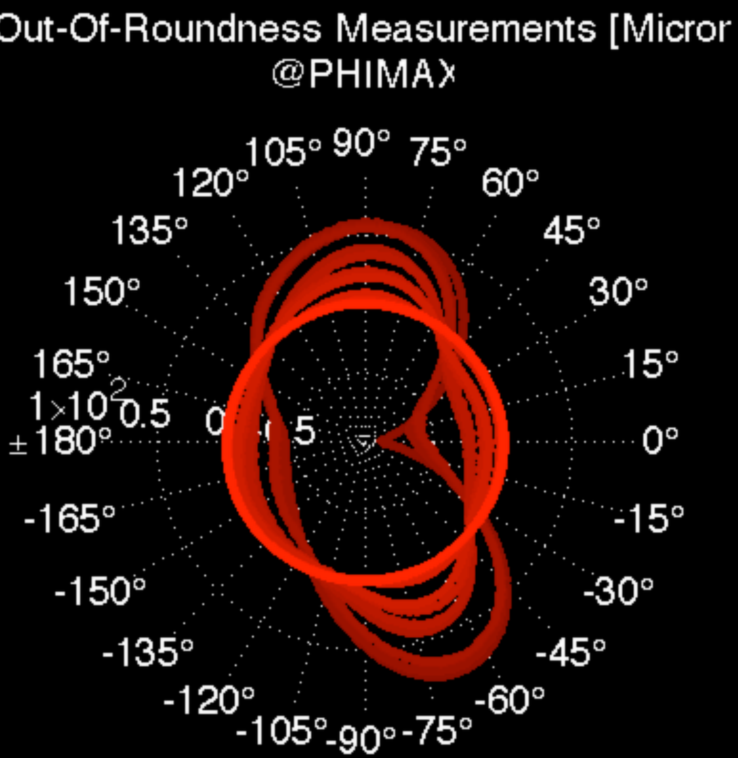
Objectives:

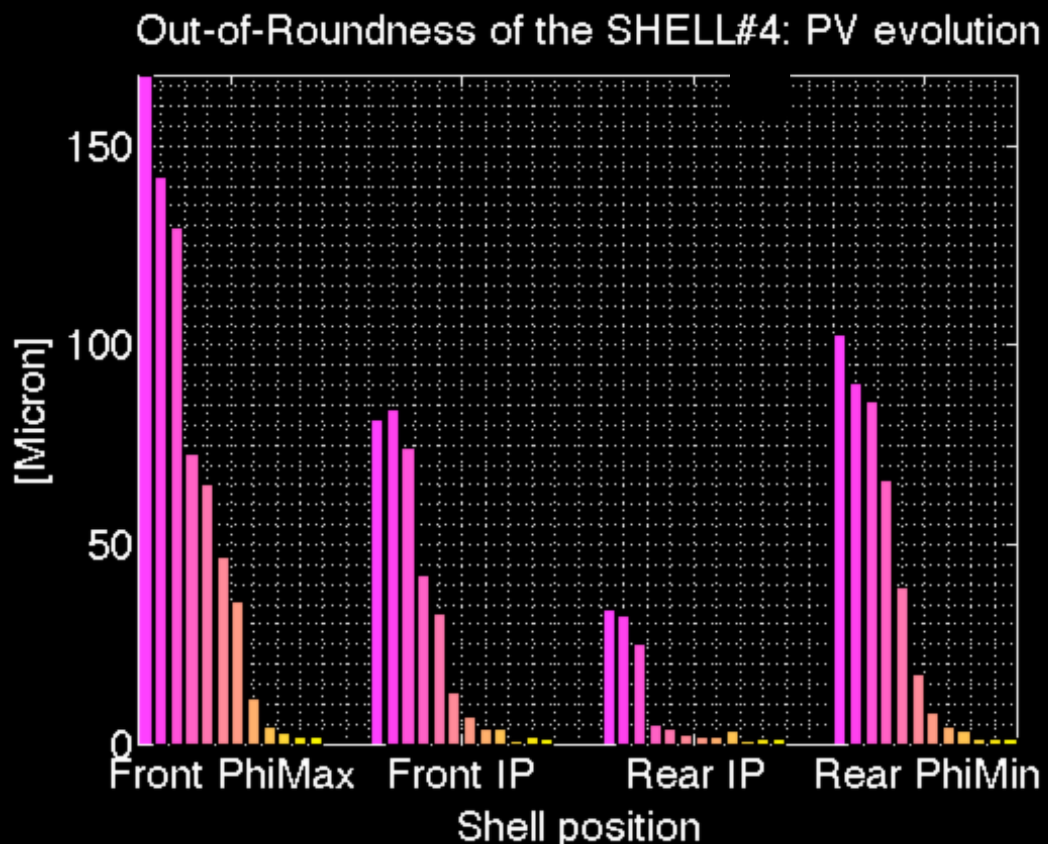
- OOR correction
- Low frequency profiles correction



Grinding wheels with different grain size available: D30, D20, D5, D3, D1 and D0.5

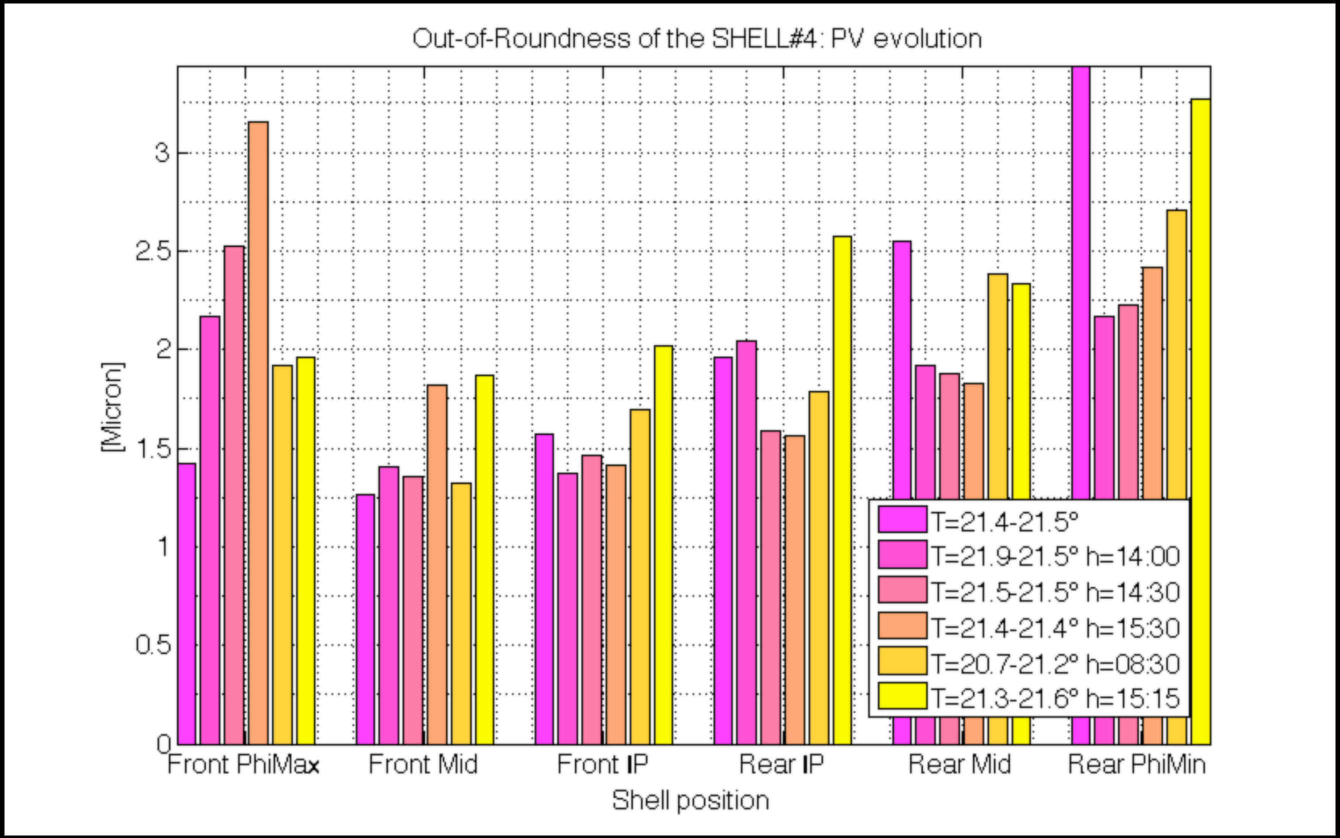
OOR correction with fine grinding





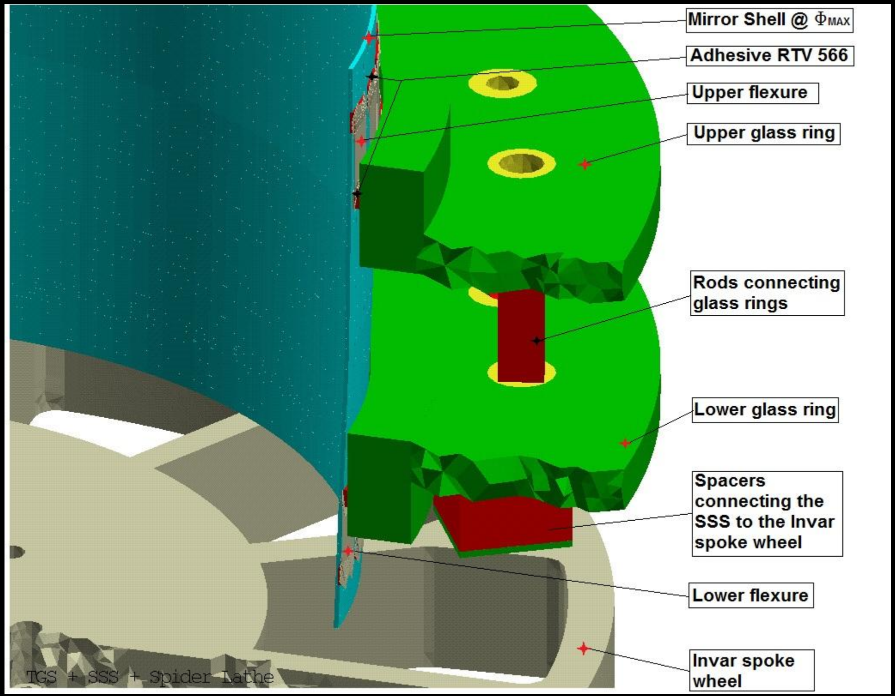
The process has converged to OOR with PtV around 1.5 microns corresponding to HEW contribution 1.3”

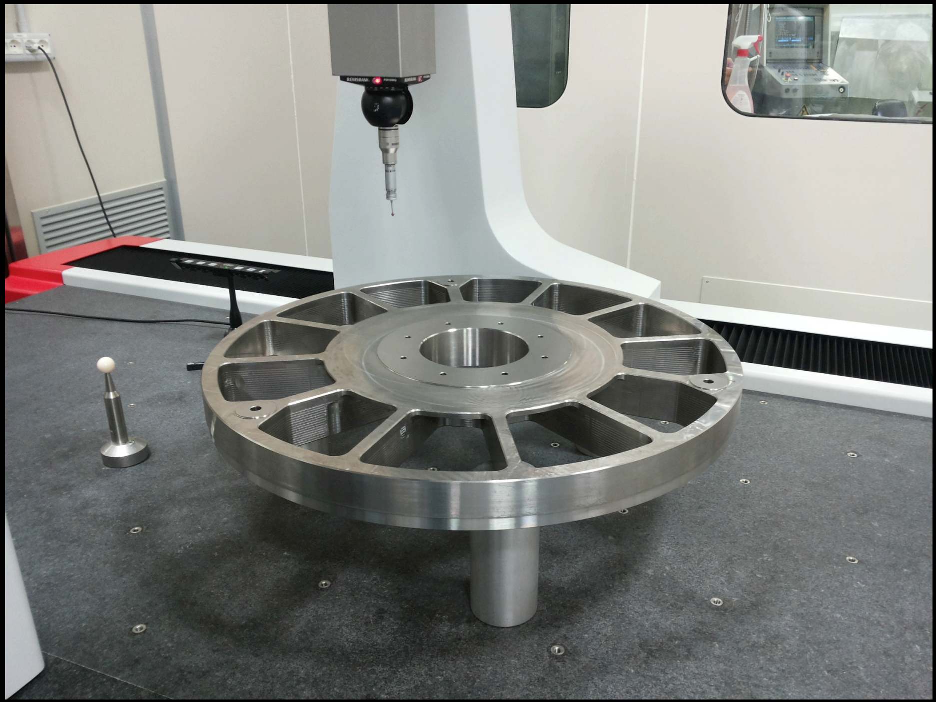
OOR repeatability problem



- In the present set-up, temperature effects limit the accuracy
- Further corrections are needed with ION BEAM (target 500nm PtV)
- Improvements in the SSS system: invar interface

New invar disk in the SSS

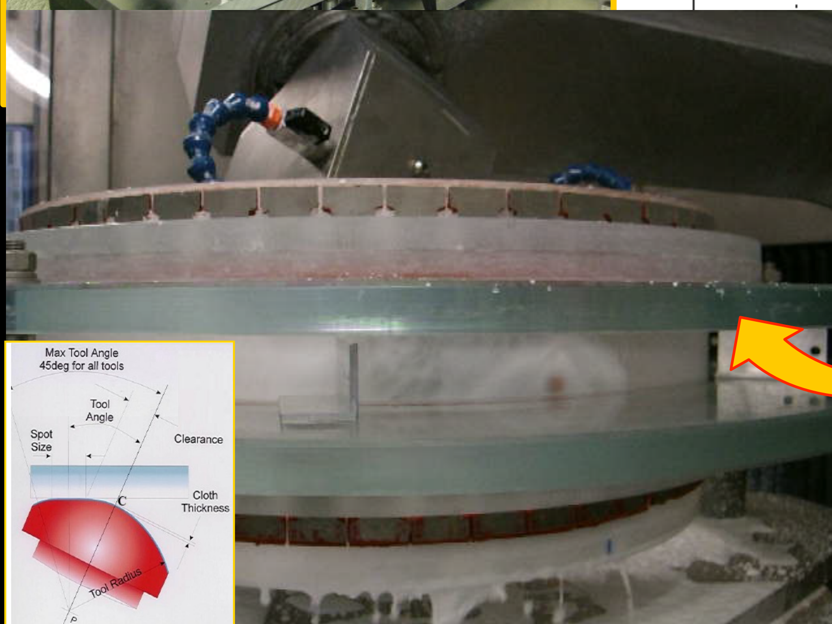


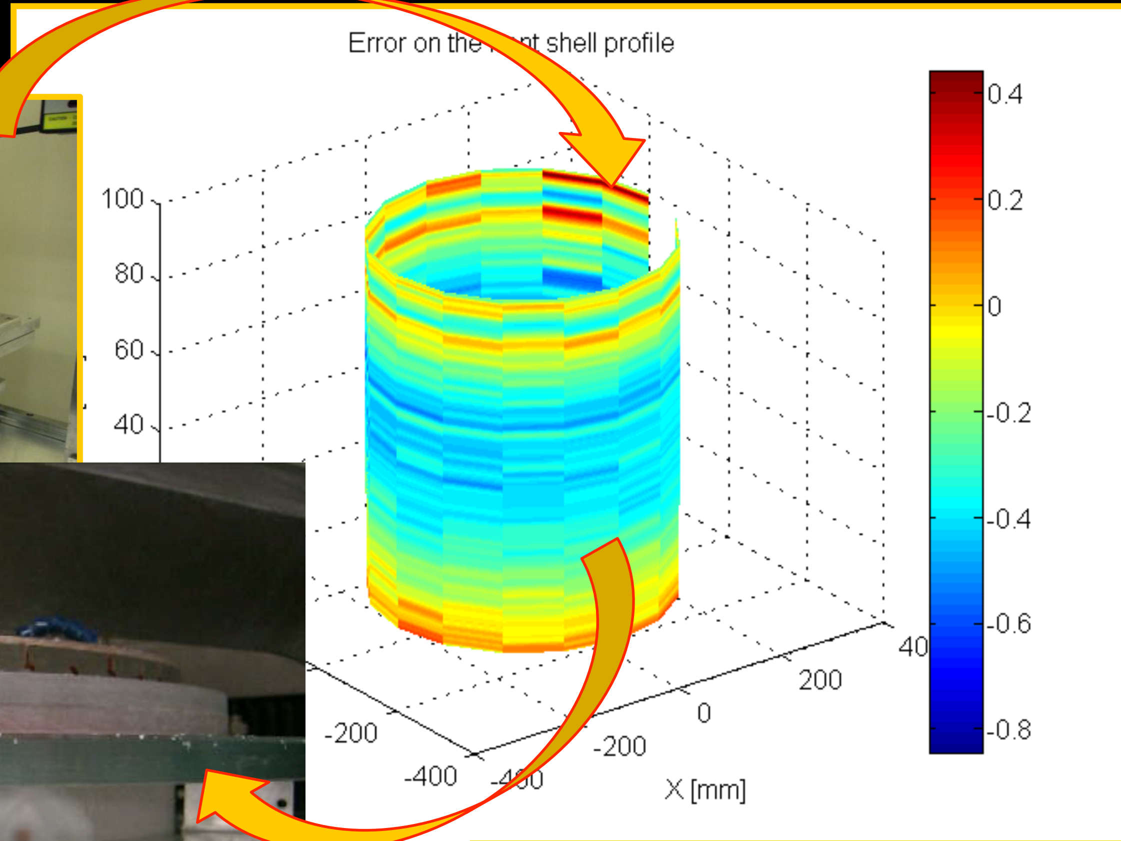


- Interface compatible with the lathe set-up
- To remain part of the SSS + shell system during the polishing phases/ ion beam figuring
- To remain part of the SSS + shell system during calibration @Panter

➔ Never dismount up to integration of the shell in the final spider system:

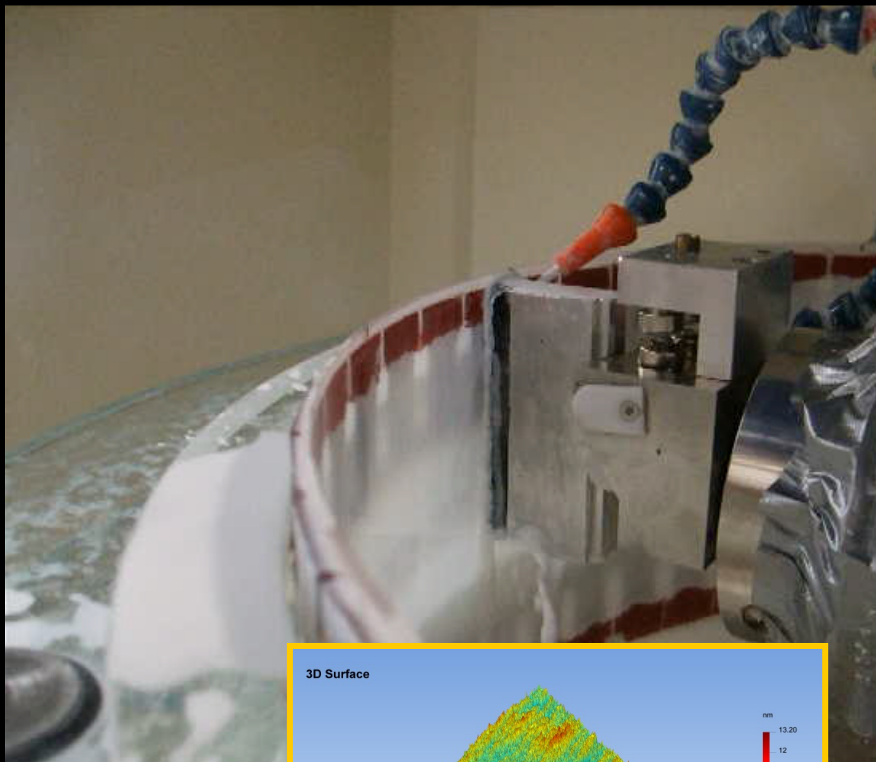
Super-polishing (@Zeeko Ltd)



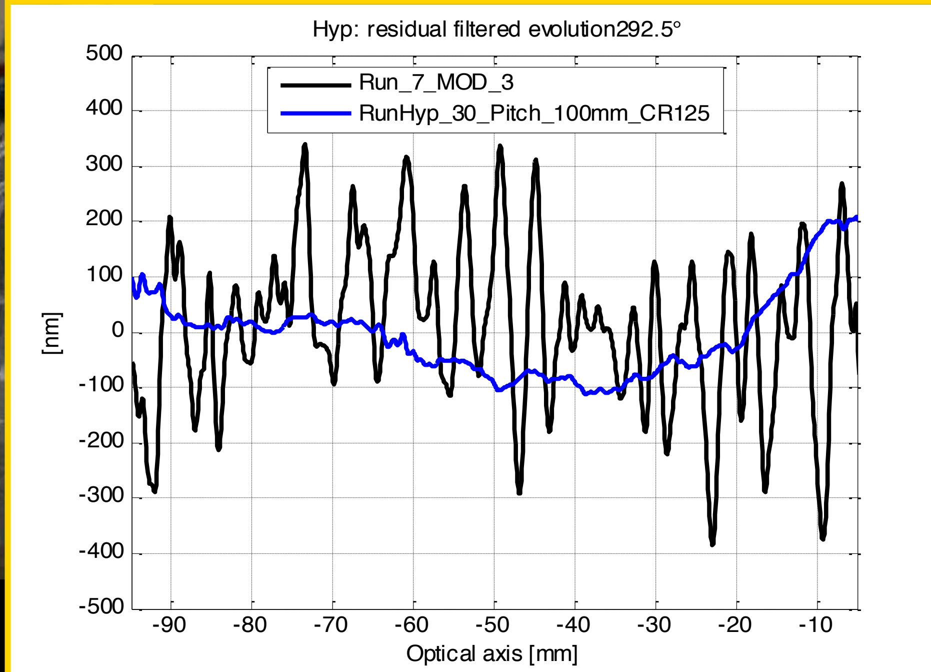


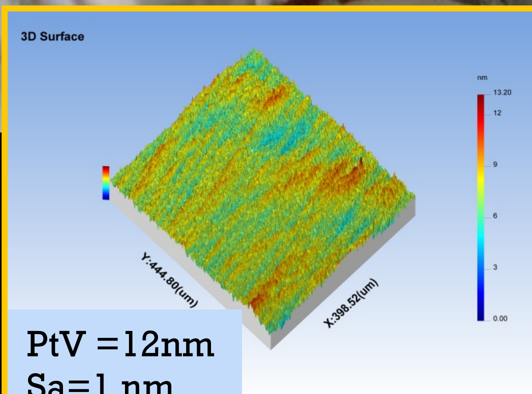
Objectives:
- SSD removal
- Low frequencies profile & OOR correction

Super-polishing (@Zeeko Ltd)



Objectives:
- mid-frequency removal
- Micro-roughness correction

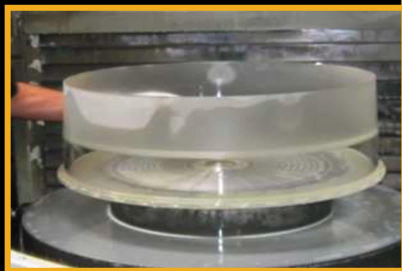


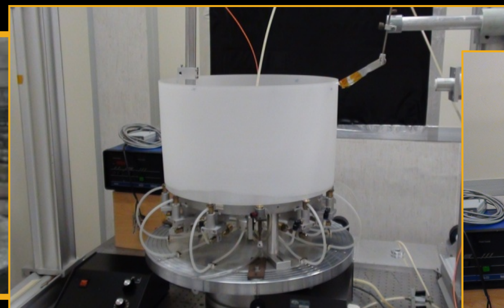


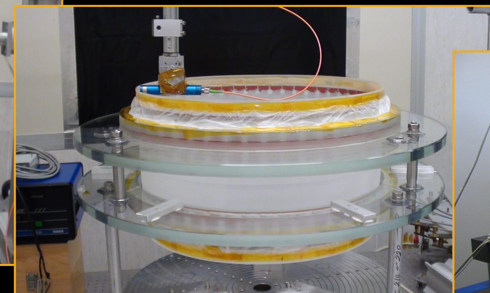
PtV =12nm
Sa=1 nm

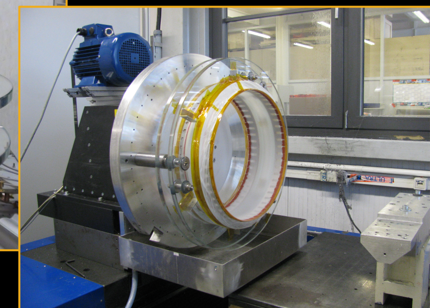
RT of the data:
Low freqency: HEW = 6”
Low + mid frequency: HEW =14”
→ Too much !!!

New process flow

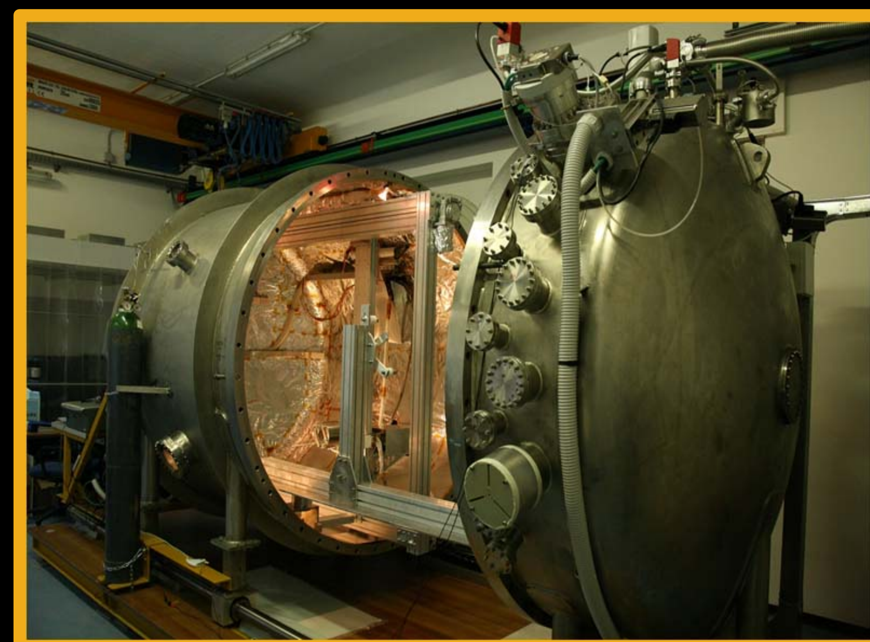




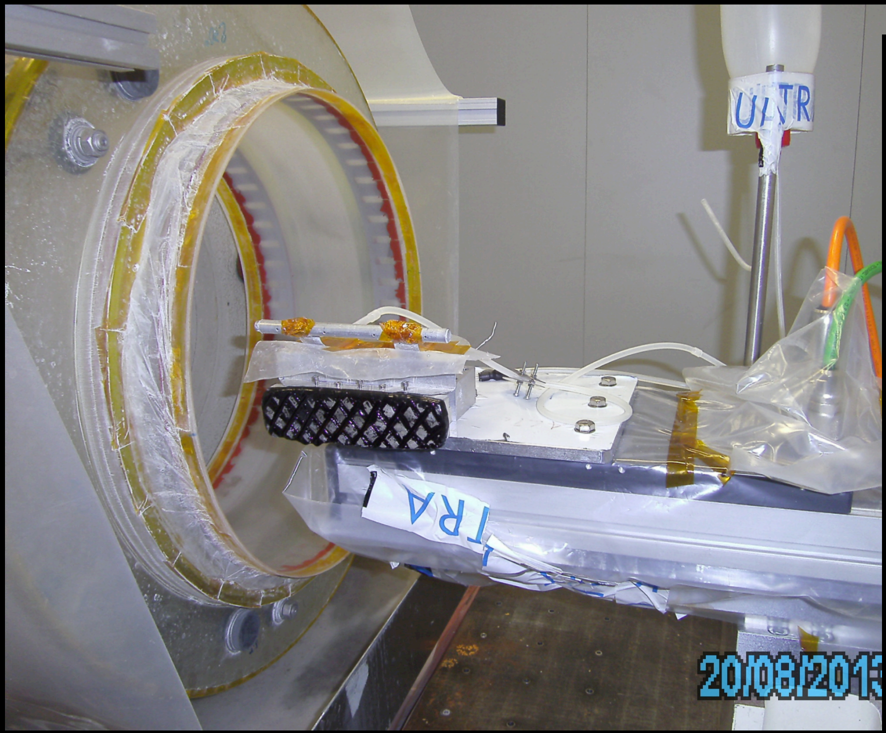


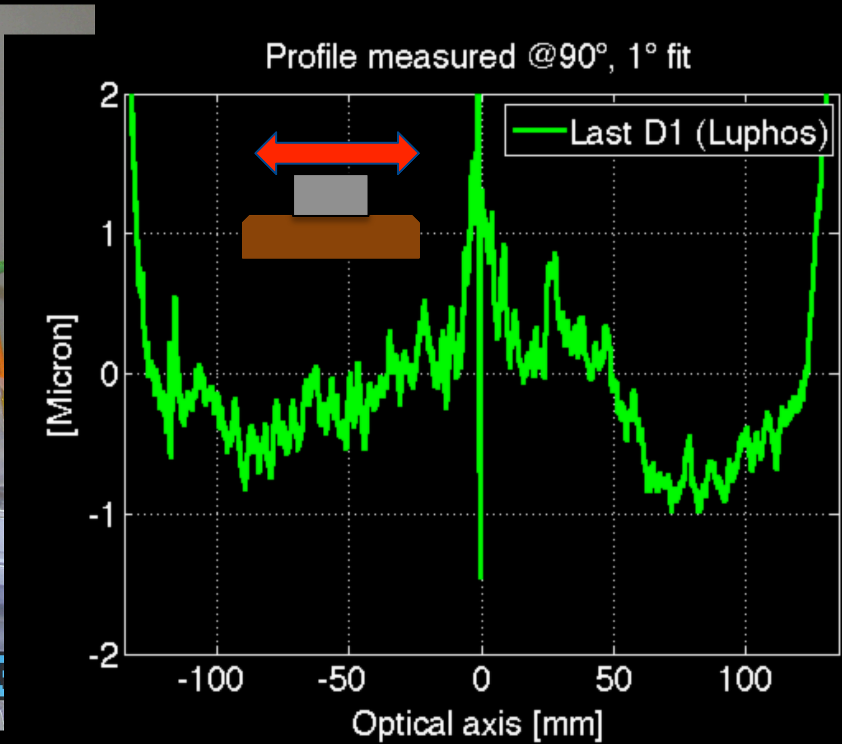


The first part is the same, up to fine grinding



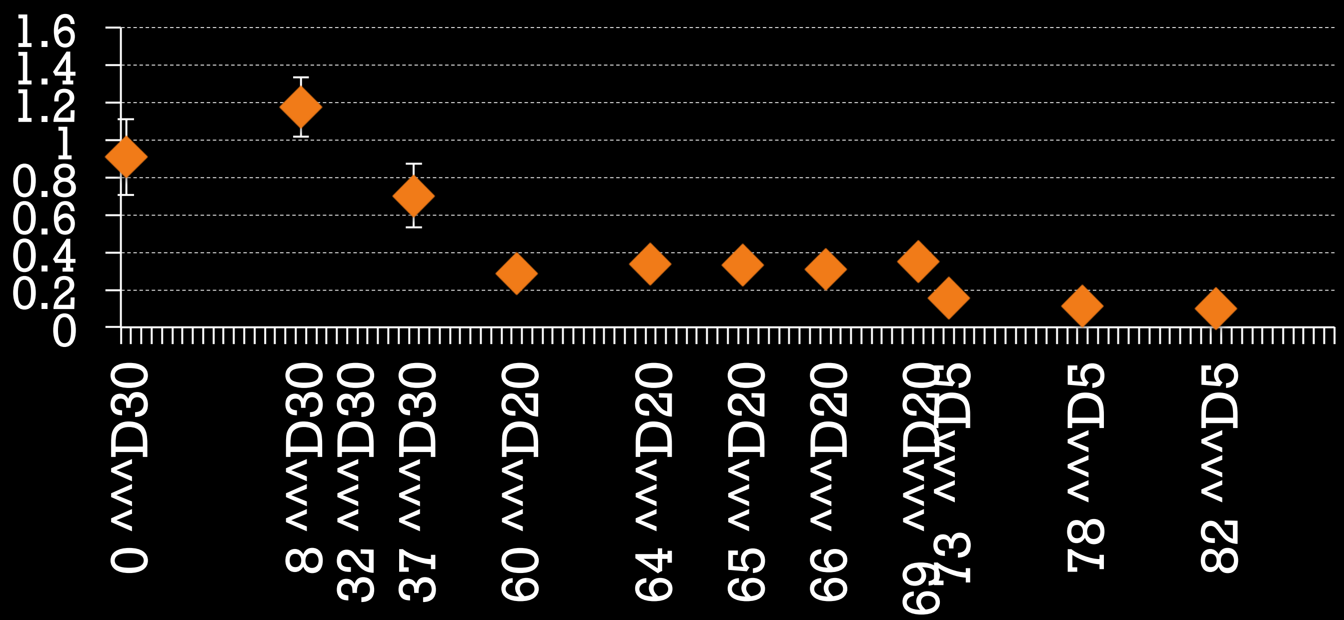
Polishing phase: on the lathe





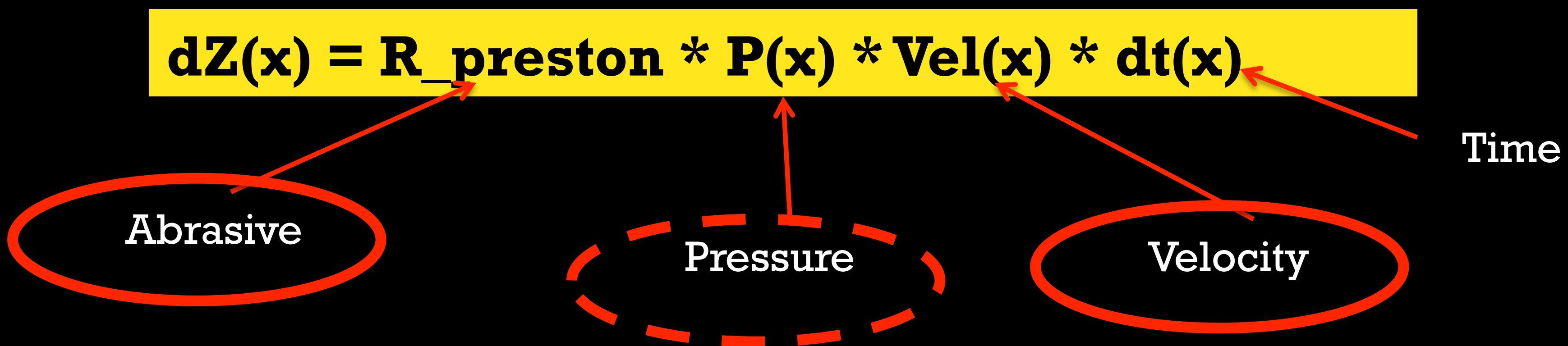
- Expected errors after the grinding are of the order microns
- Micro-roughness around 50 nm rms (1mm scale)
- Max force 1kg (the shell is thin !!!)

Roughness

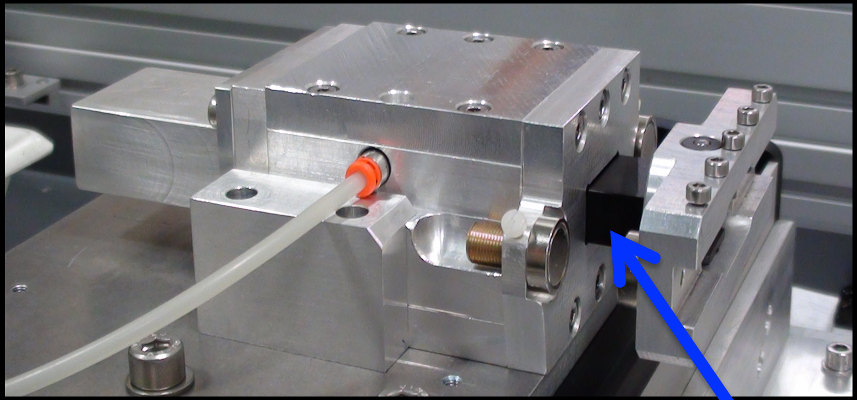


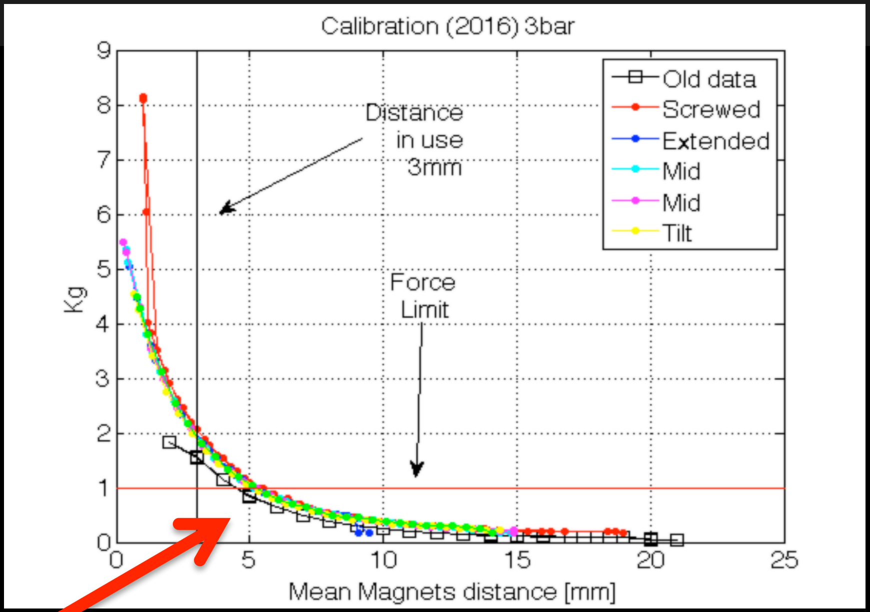
On 17.5mm length

How to speed up (Preston law):



New pitch tool and high speed carriage

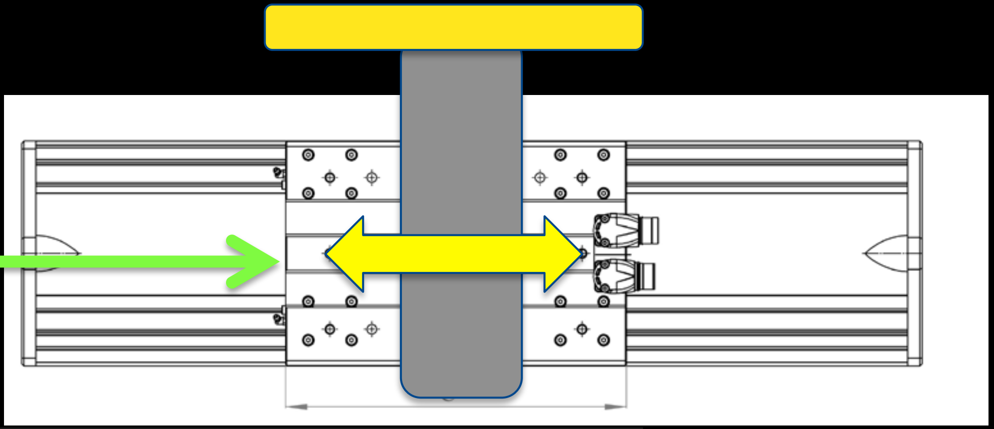




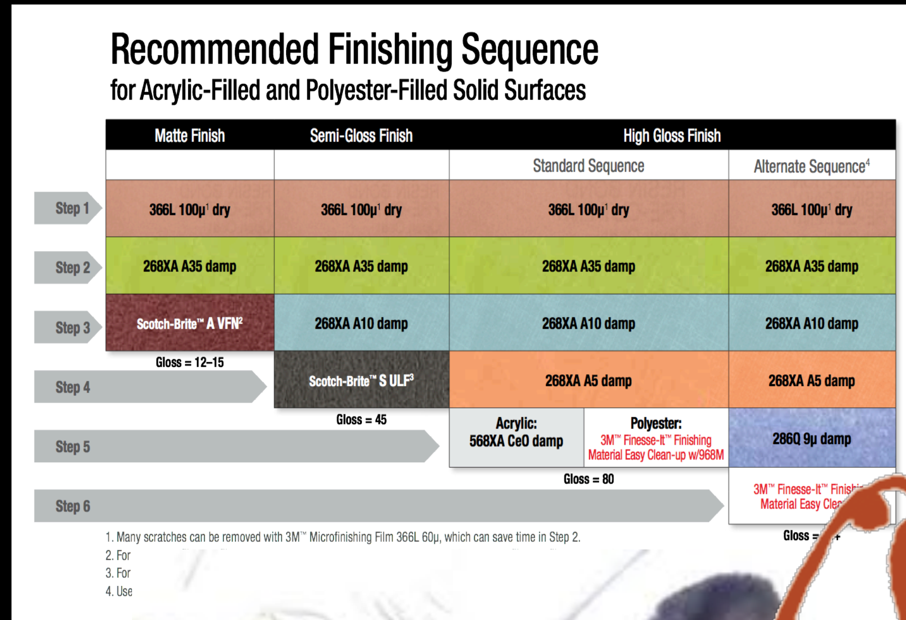
- Pitch tool pad mounted on an air bearing carriage: NO FRICTION

- Magnets @variable distance: ADJUSTABLE FORCE

- Linear carriage: HIGH FREQUENCY MOVEMENTS (15Hz on 2mm)



Polishing with Trizact (3M)



Recommended Finishing Sequence
for Acrylic-Filled and Polyester-Filled Solid Surfaces

	Matte Finish	Semi-Gloss Finish	High Gloss Finish: Standard Sequence	High Gloss Finish: Alternate Sequence[4]
Step 1	366L 100µ[1] dry	366L 100µ[1] dry	366L 100µ[1] dry	366L 100µ[1] dry
Step 2	268XA A35 damp	268XA A35 damp	268XA A35 damp	268XA A35 damp
Step 3	Scotch-Brite™ A VFN[2]	268XA A10 damp	268XA A10 damp	268XA A10 damp
Step 4	Gloss = 12–15	Scotch-Brite™ S ULF[3]	268XA A5 damp	268XA A5 damp
Step 5		Gloss = 45	Acrylic: 568XA CeO damp / Polyester: 3M™ Finesse-It™ Finishing Material Easy Clean-up w/968M	286Q 9µ damp
Step 6			Gloss = 80	3M™ Finesse-It™ Finish… Material Easy Clea…
				Gloss =

1. Many scratches can be removed with 3M™ Microfinishing Film 366L 60µ, which can save time in Step 2.
2. For
3. For
4. Use

Advantages:
- Speed up polishing phase
- No slurry (simpler shell cleaning procedure)
- Deterministic (pad surface status Vs expected results)

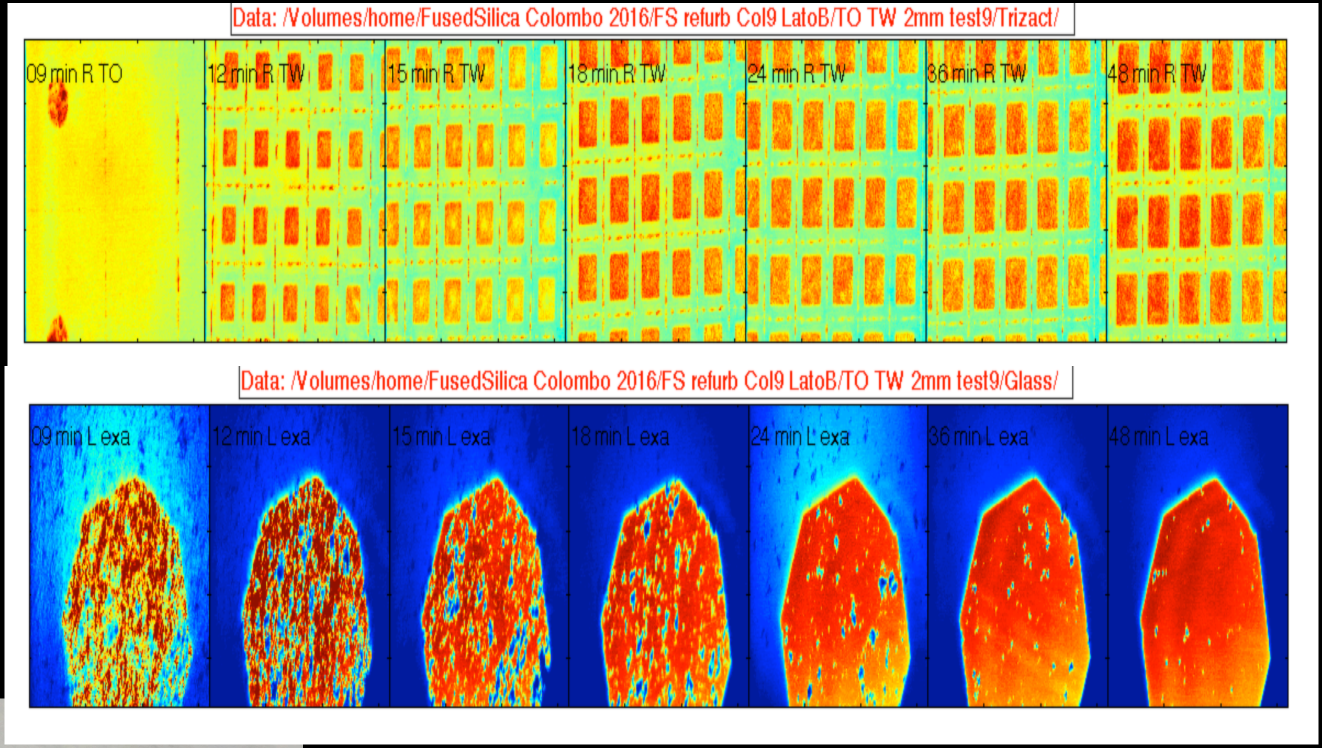
Polishing trials on samples

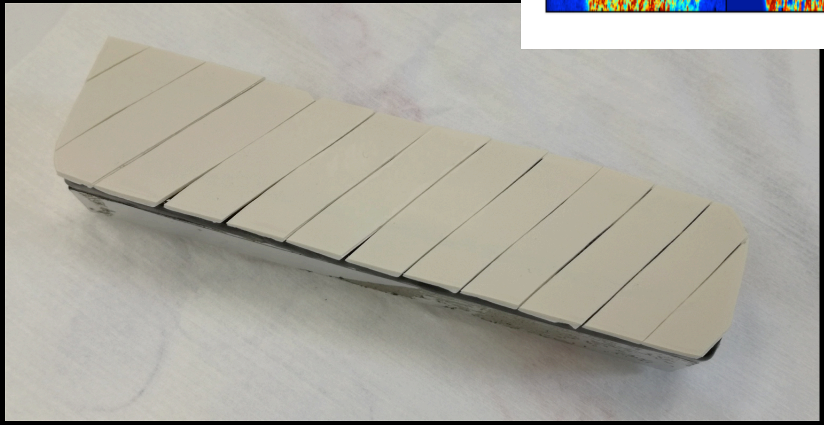
CHARACTERIZATION:

- Removal rate
- Micro-roughness evolution

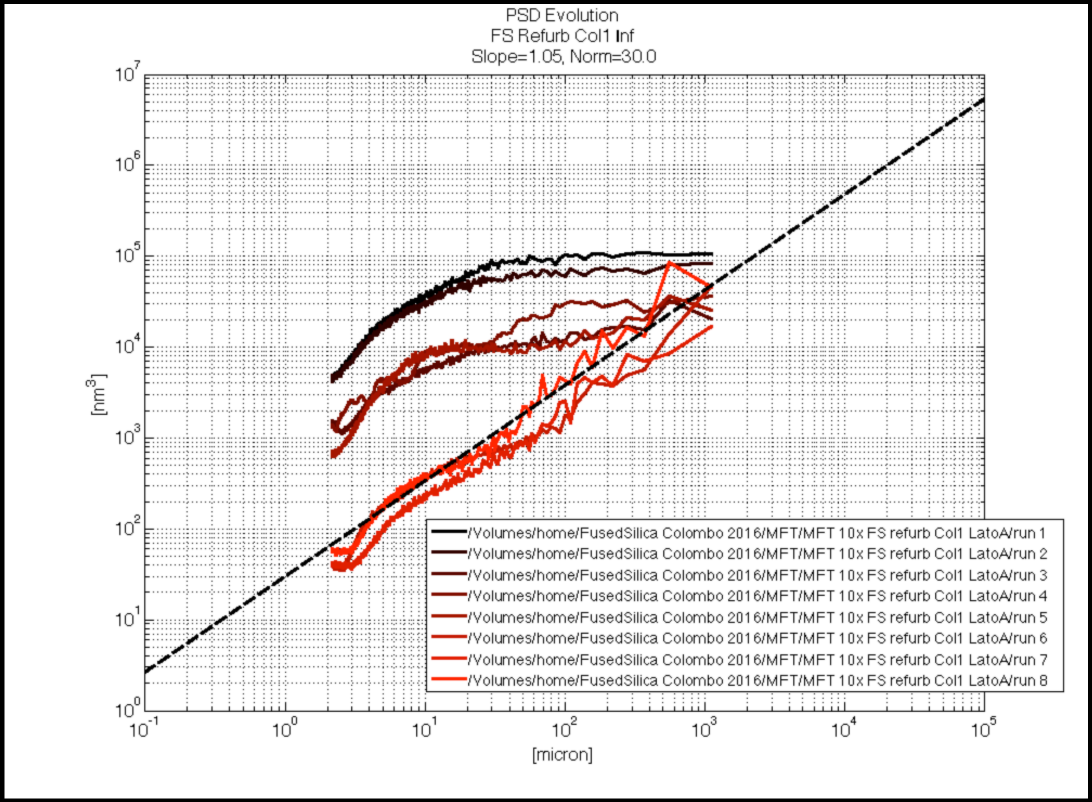
OPTIMIZATION:

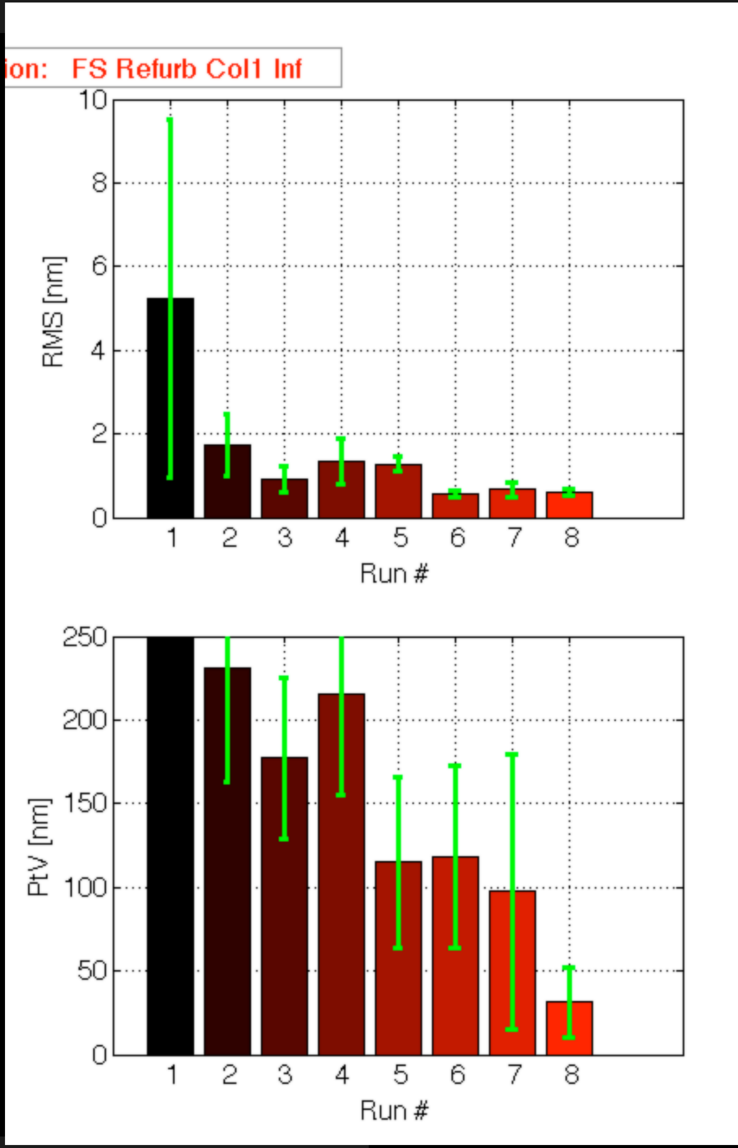
- Fixation set-up
- Pressure
- Amount of Water
- pH
- Pattern





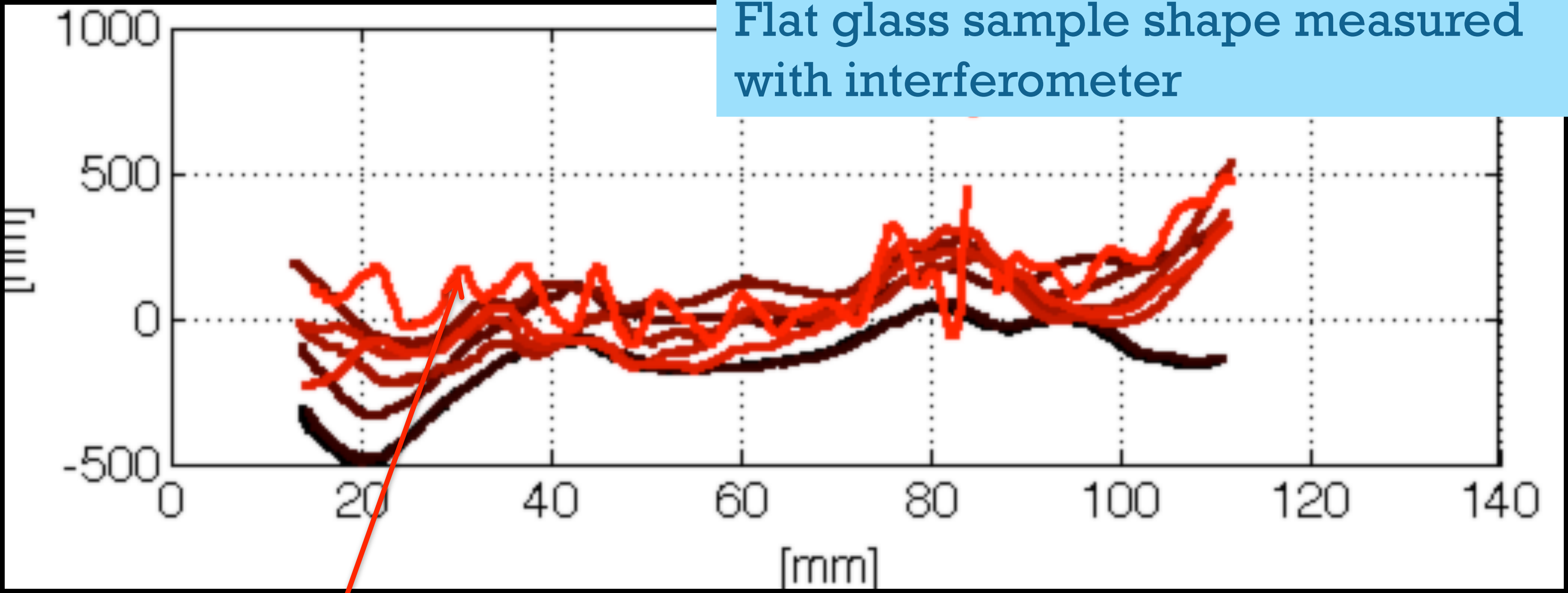
Polishing trials with Trizact: micro-roughness





Example of the micro-roughness evolution during polishing steps

Polishing trials with Trizact: shape



Flat glass sample shape measured with interferometer

- The shape of the polished area changes is maintained within few hundreds of nanometers. HEW variations within few arcsec.
- Pitch tool movements can be optimized to avoid undesired mid-frequencies features

Main ingredient of the process: Ion beam figuring

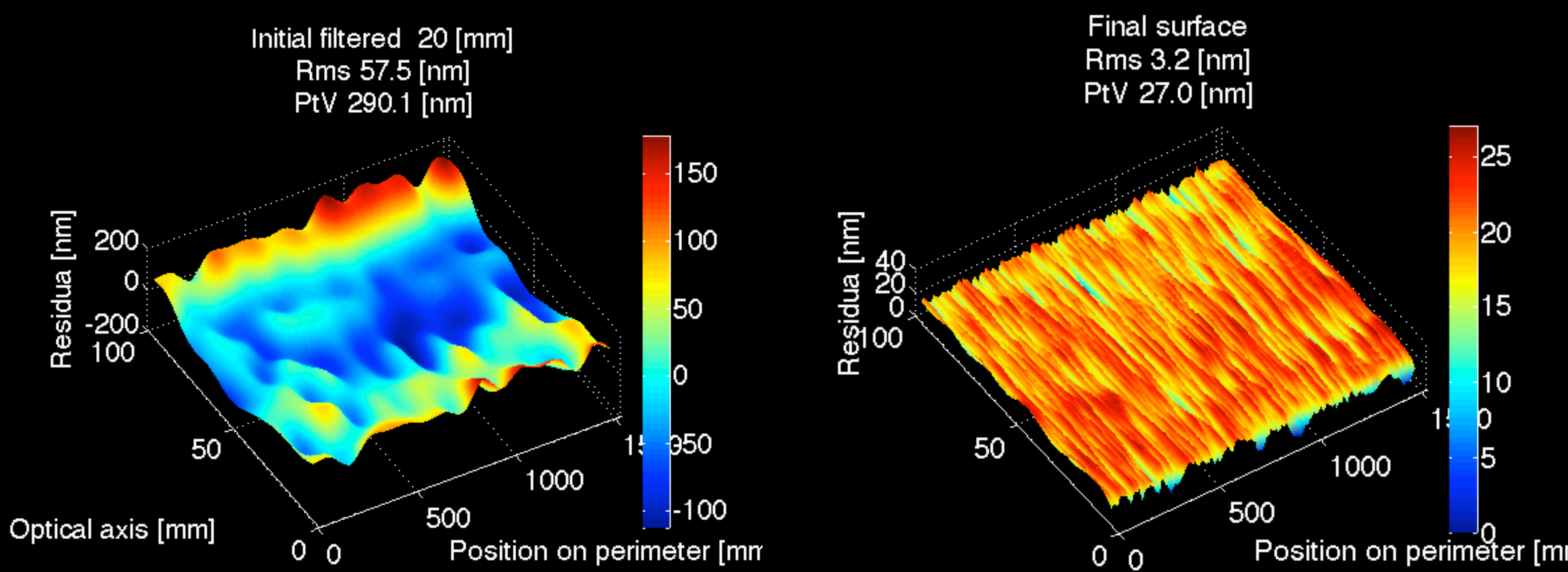
After the surface is polished,
to correct low frequency figure errors

PRO:
- Deterministic process
- Non contact
- Micro-roughness preserved (or improved)

AND…

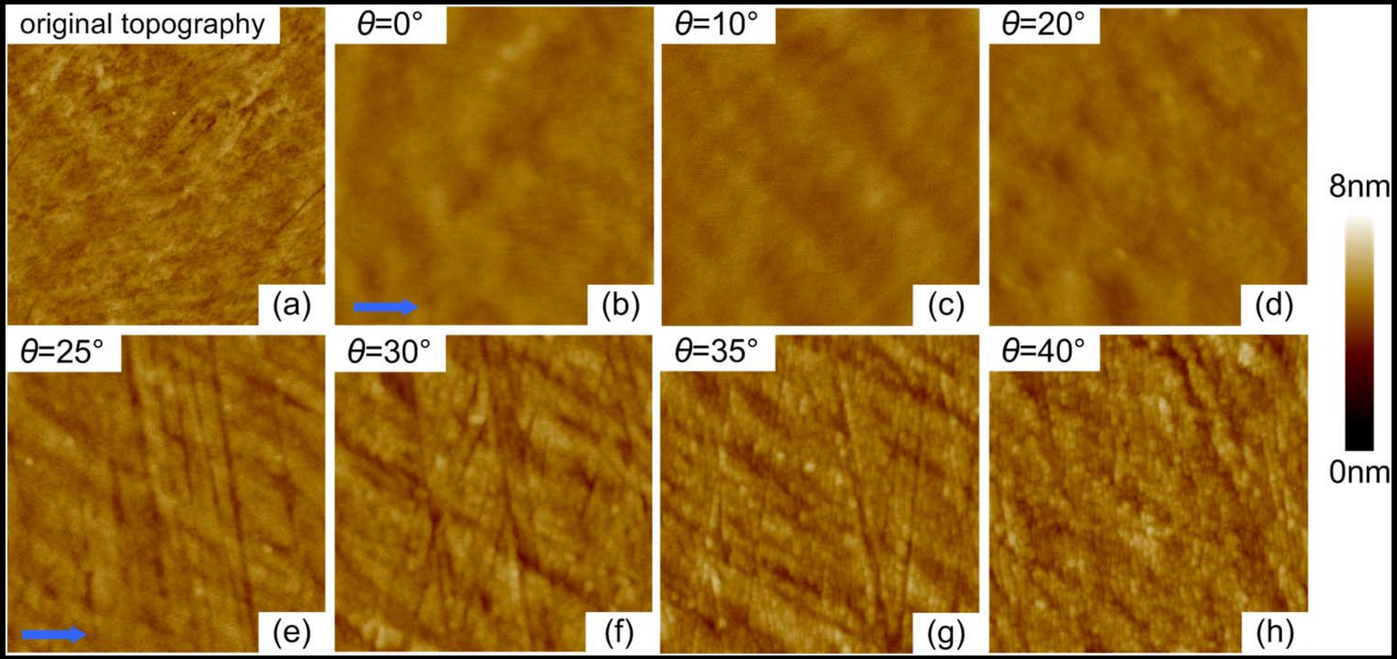
- Very large facility already available @INAF-OAB. Rotary table to be implemented

Ion beam: expected results from simulation



Ideally the Ion beam process is able to converge toward final rms of around 3nm, removing completelly low frequency errors in both longitudinal and azimuthal directions. (HEW <<1”).

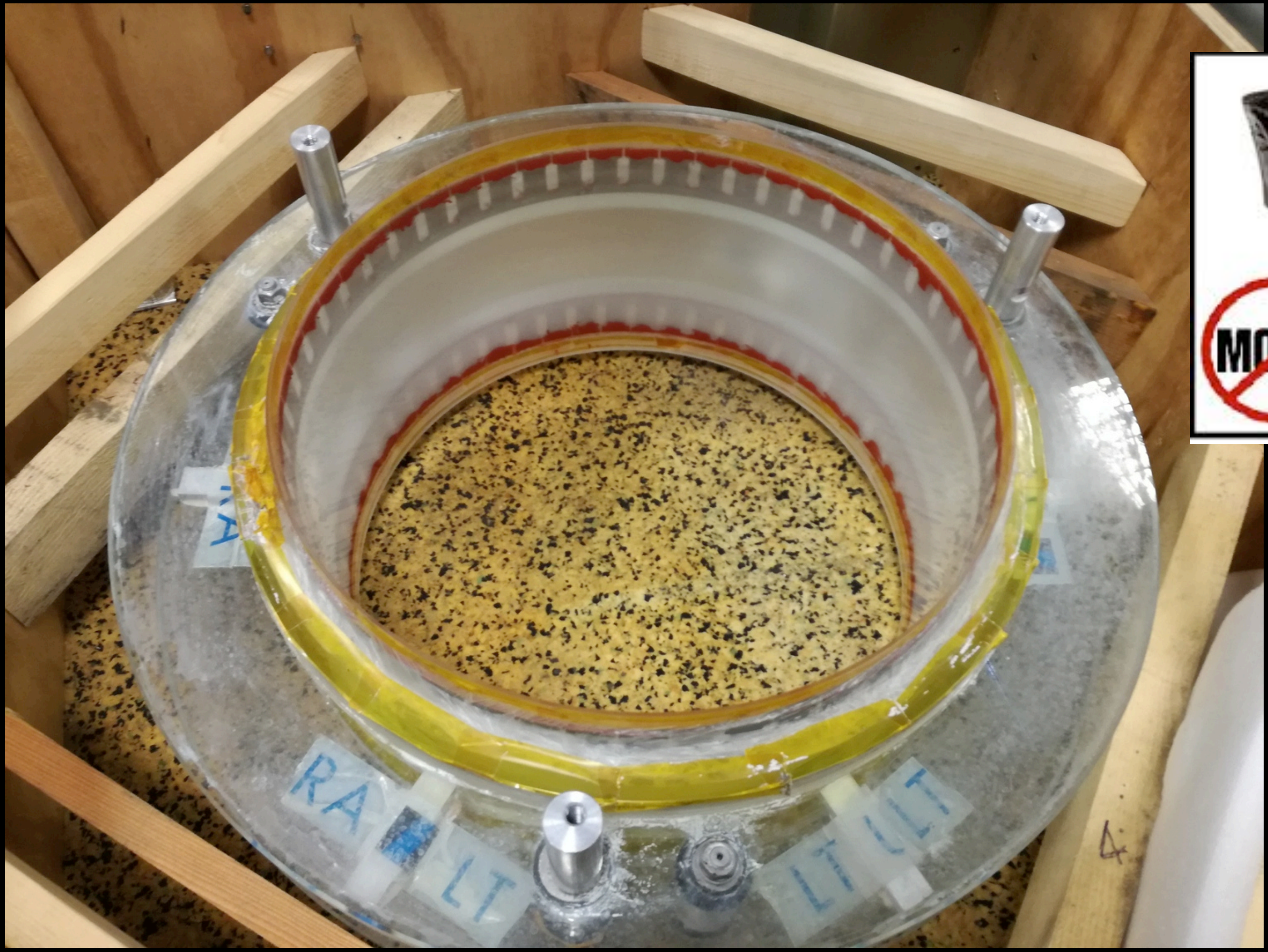
Important note: Micro-roughness Vs Ion Beam



Wenlin Liao, Yifan Dai, Xuhui Xie, and Lin Zhou, Appl. Opt. 52, 3719-3725 (2013)

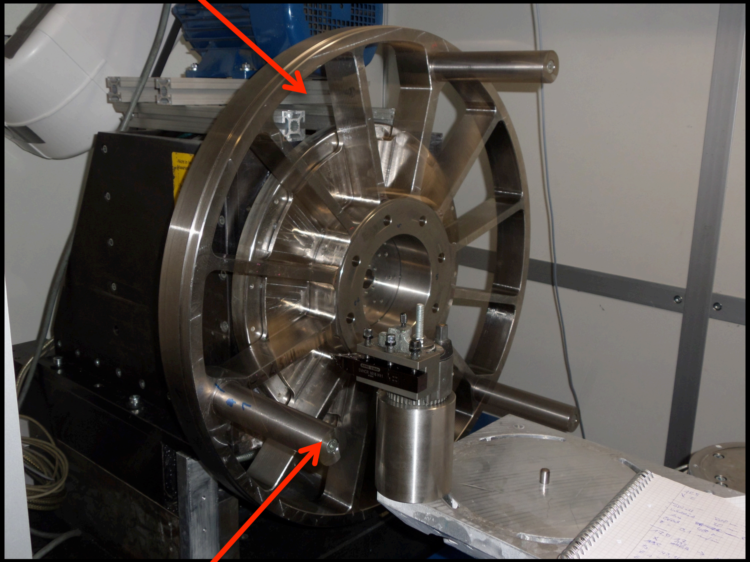
Starting from fused silica sample With Rq = 0.45nm, for incidence angles lower than 20°, Rq is 0.2nm after the ion beam figuring.

Activities on Shell#4… were in ‘’stand-by’’

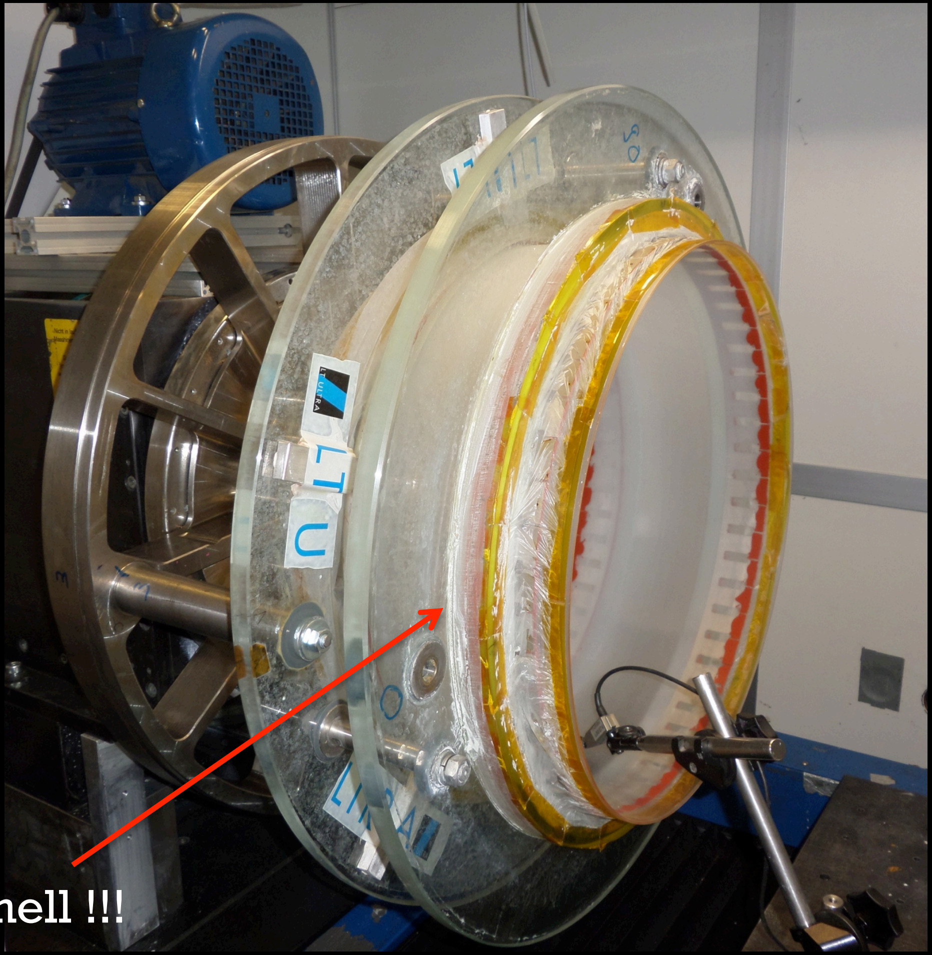


... just restarted!!!

New invar interface

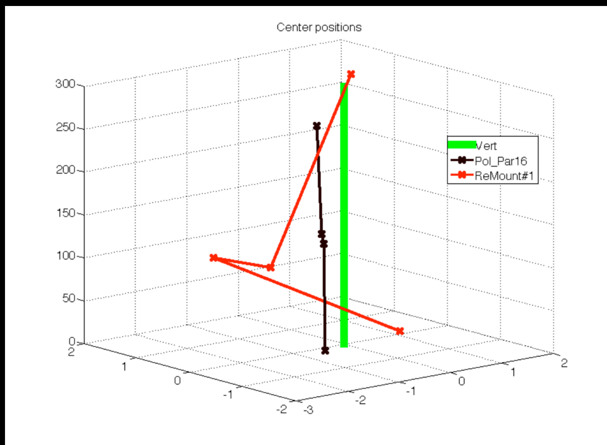


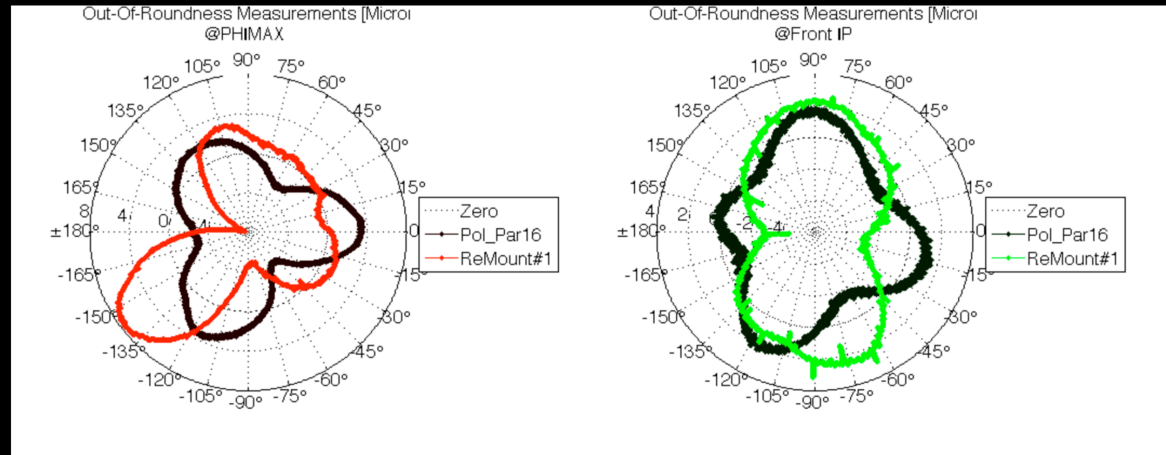
New titanium Spacers

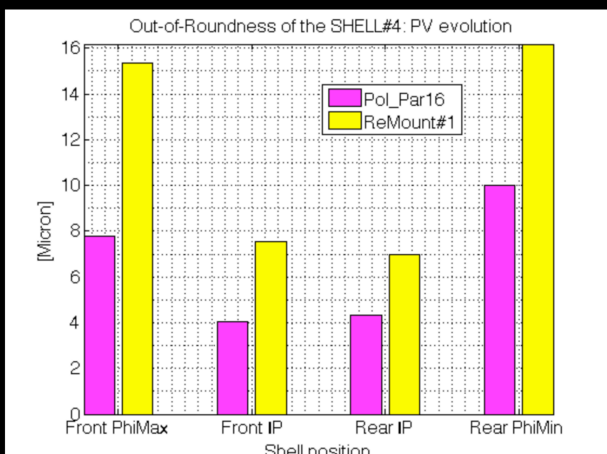


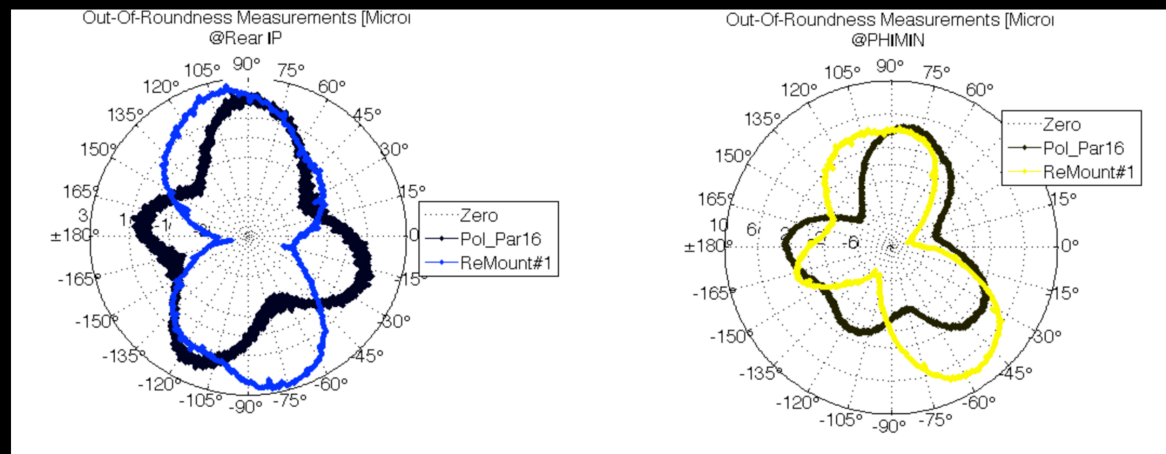
Old shell !!!

With a good news: not to much deformed!









How much does it cost?

Credits, CNN Money

Current prototypal shell

Material

- Raw shell: 6keuro
- Jig (SSS+Invar): 25keuro

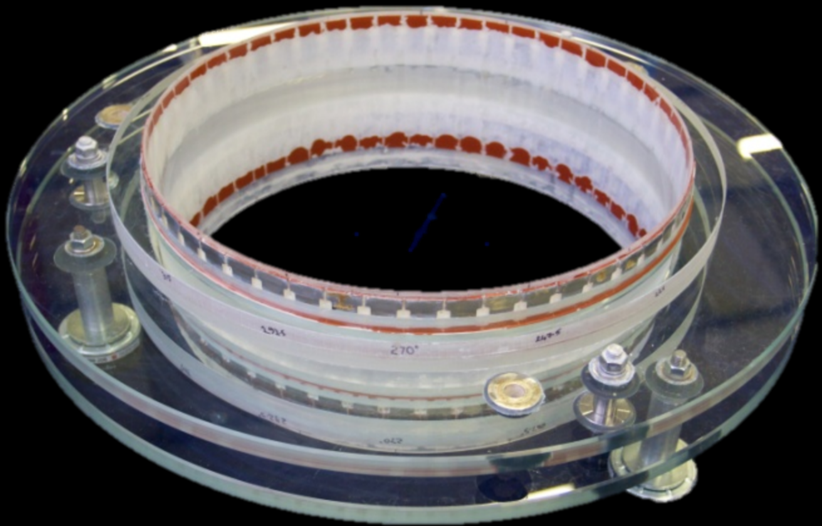
Time:

- Integration in SSS: 2weeks
- Grinding: 4 weeks
- Polishing: 4-8 weeks
- Ion Beam: 2 weeks

For final shell

- Initial Chemical etching
- Coating
- Integration in the structure

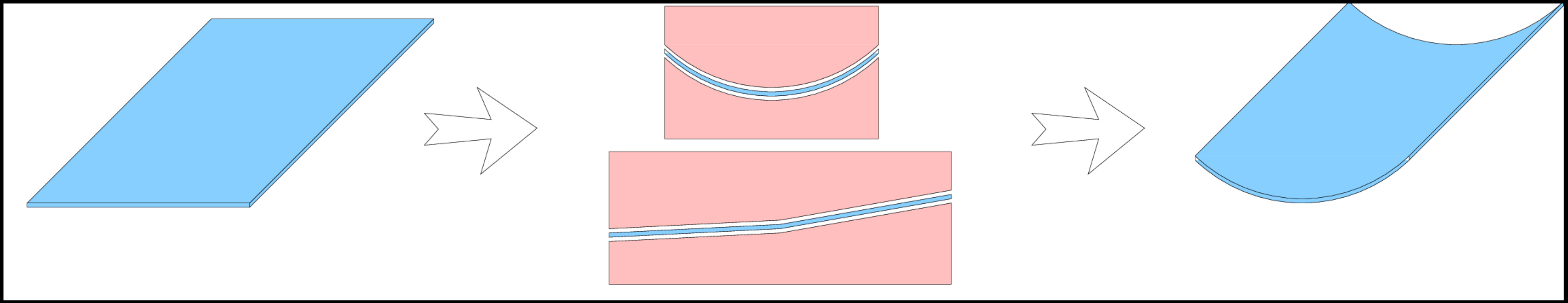
Monolithic… or Segmented



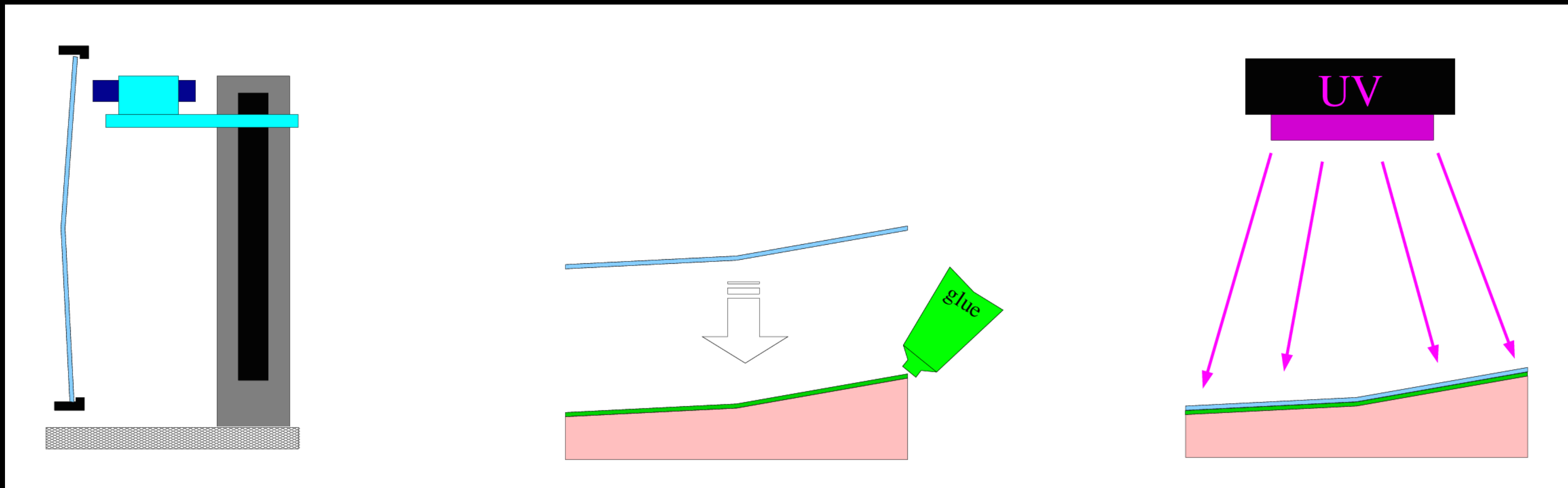
Main differences:
- Substrates procurement
- Supporting system
- Direct polishing on Zeeko

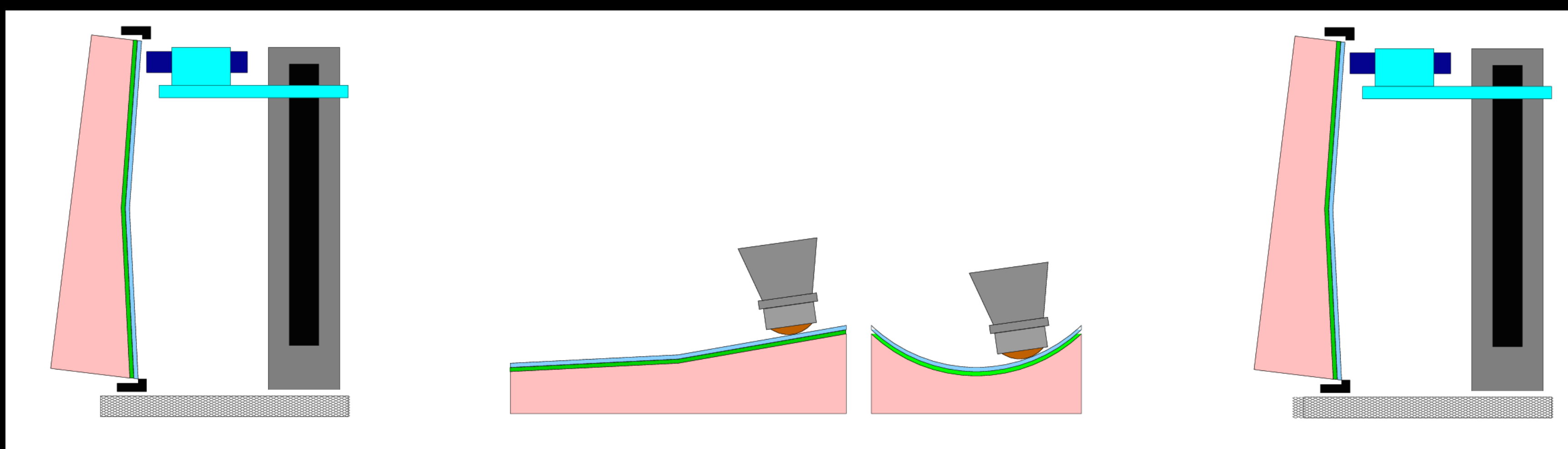
Segments: substrates procurement

– Segments grinding
– Pre-shaping via slumping
– Full monolithic shells grinding and then segments produced cutting the shell

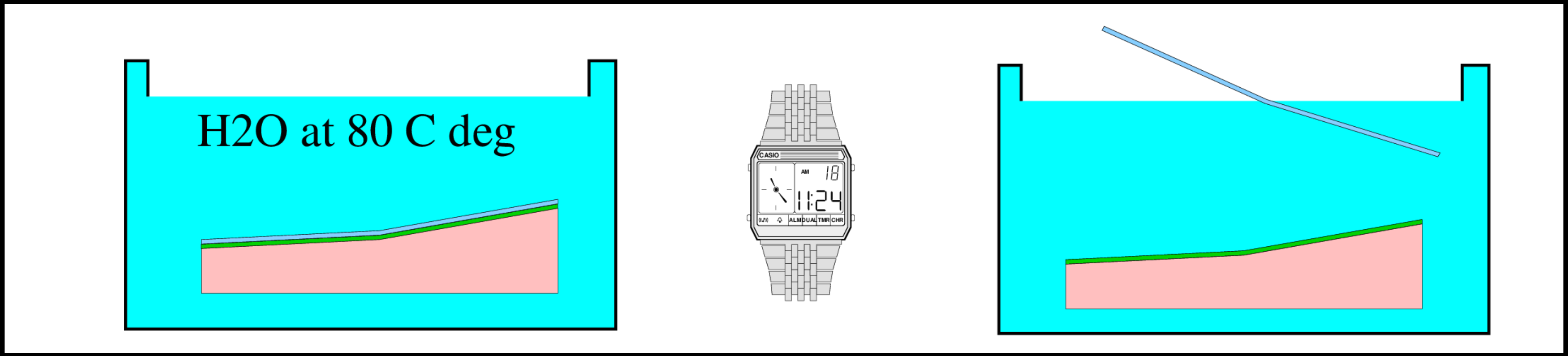


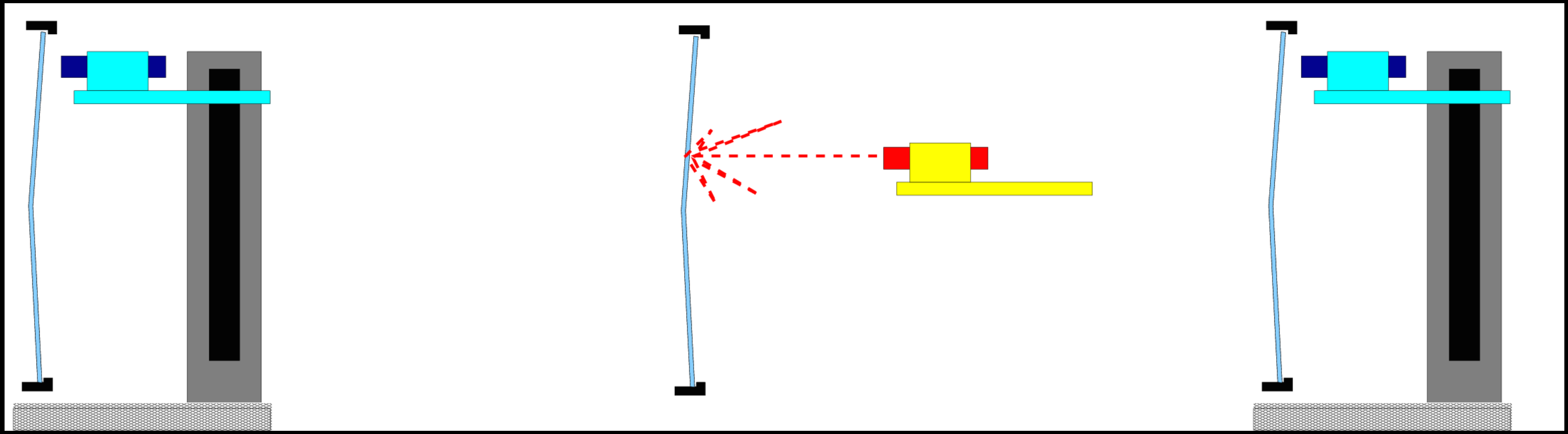
Segments: production flow (1/2)



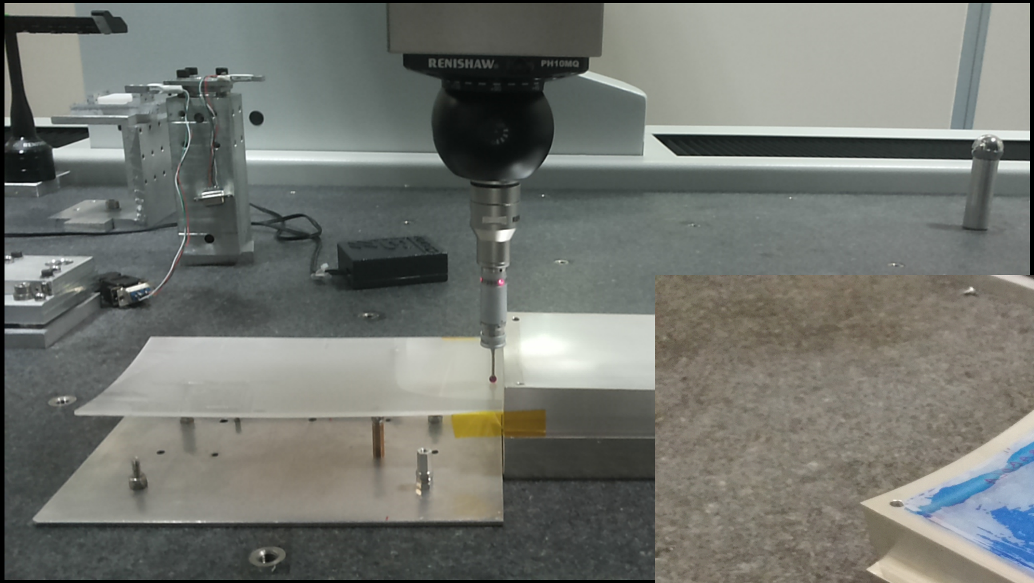


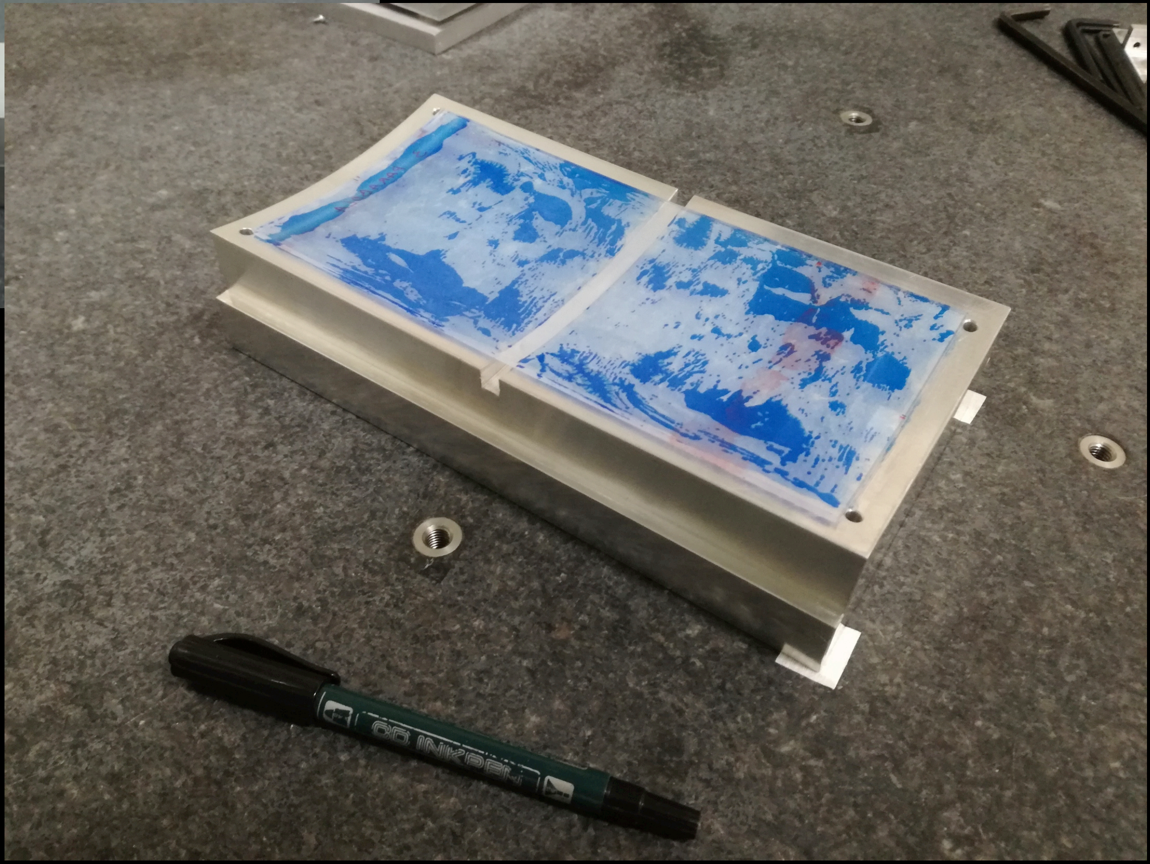
Segments: production flow (2/2)



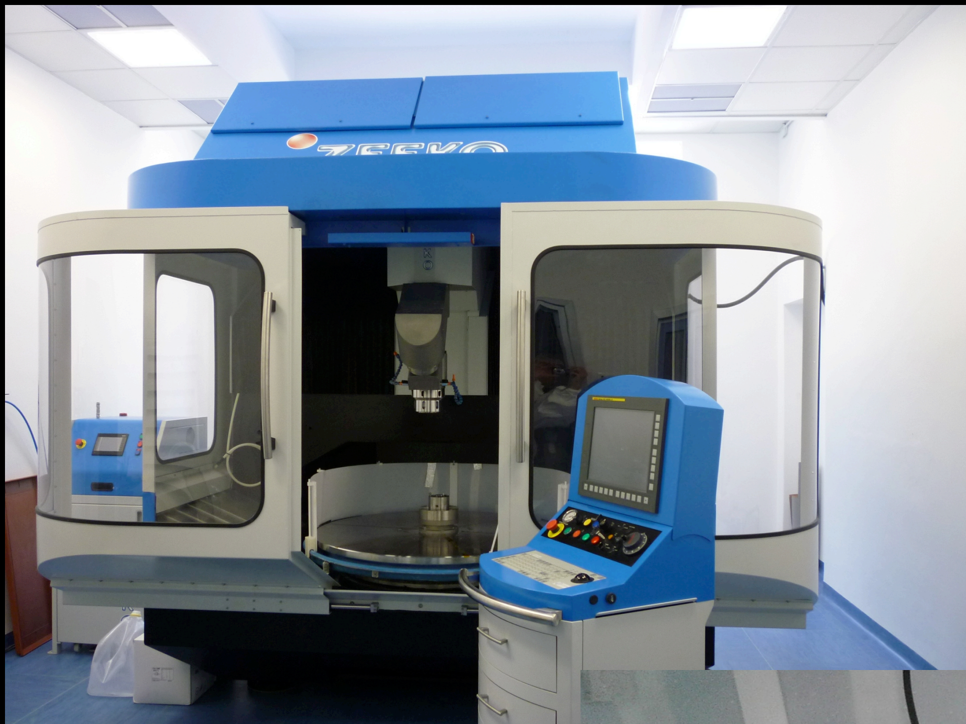


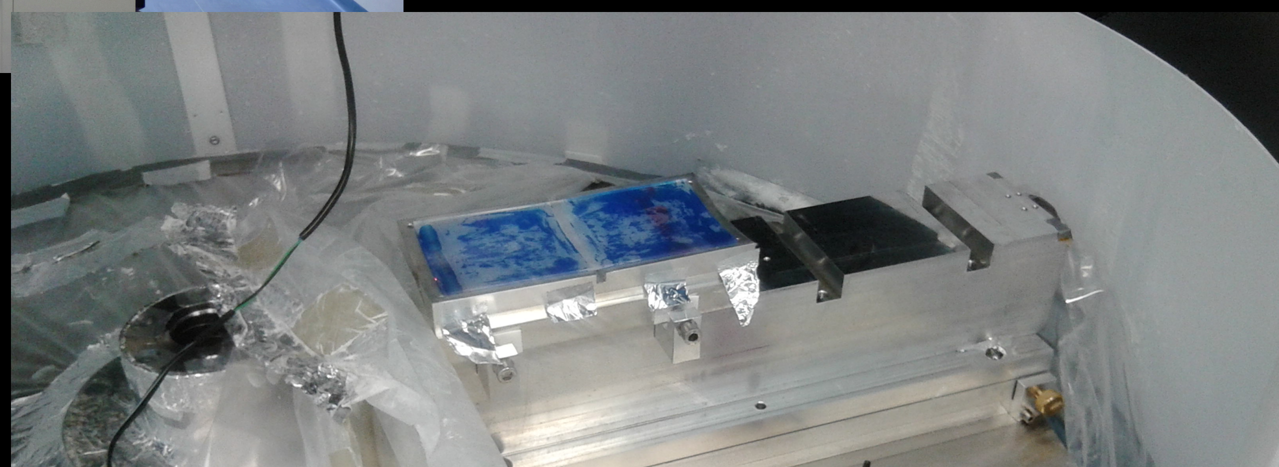
Status on segments



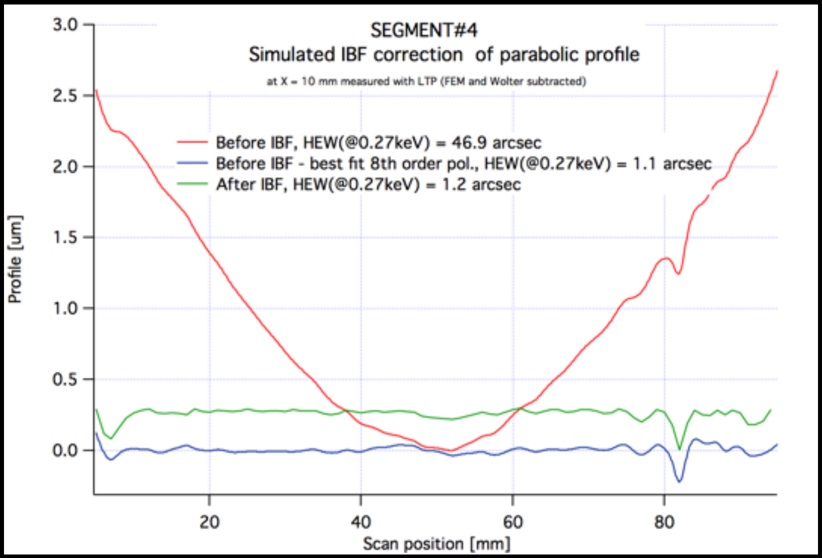


Segments on Zeeko

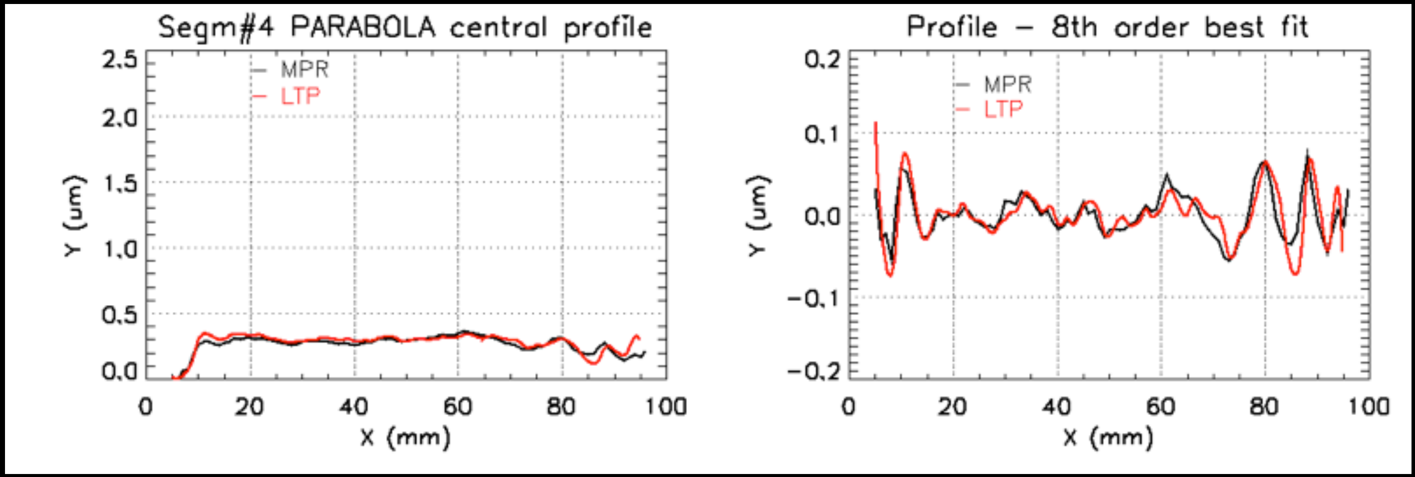




Ion beam exercise



Ion-beam correction of a previously polished segment (cut from a bonnet-polished WFXT mirror shell)



Conclusions

- A new process based on direct-polishing and ion-figuring correction of Fused Silica shells (or segments) is being set-up

- We aim to demonstrate that:
  → the Lynx angular resolution requirement can be achieve
  → the method can be used for the production of the Lynx mirrors

- Prototypal optics under development for X-ray tests in the next few months:
  → Monolithic shell#4 grinding and polishing on the lathe will be completed by the end of June. Intermediate x-ray calibration (before ion beam figuring) depending on the expected result in July. Ion beam figuring and final calibration before winter 2017.

  → Segmnents polishing and calibration before summer.