Measurement of HLEM Aspheres

High Level Expert Meeting Samples with Isara 400

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Overview

- Introduction
  - IBS Precision Engineering
  - Isara 400
- HLEM: Aspherical Lens Measurements
  - Setup & Alignment
  - Results
  - Reversal measurement

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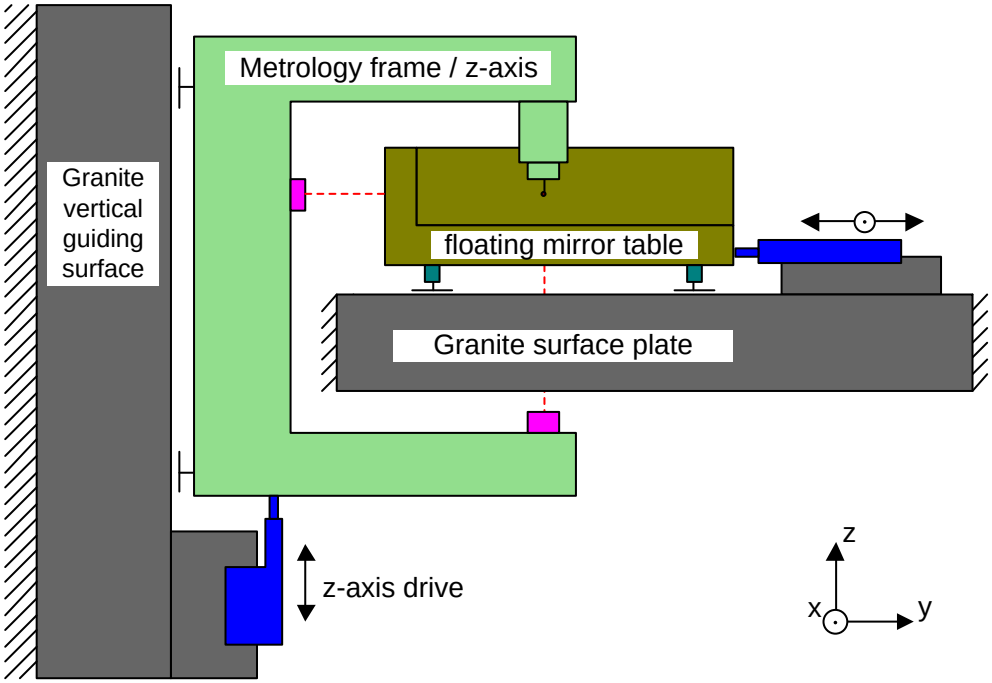
Isara 400: Next generation ultra-precision CMM

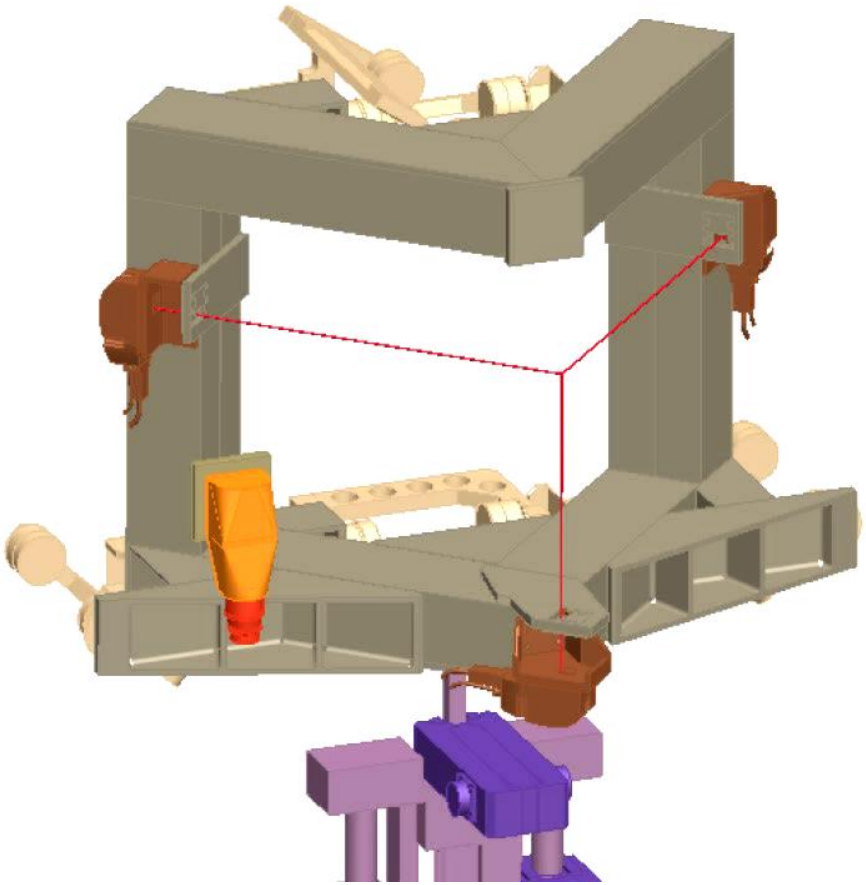
- Isara 400 offers 3D ultra-precision and a large measuring volume:
  - Measuring volume 400 x 400 x 100 mm
  - Traceable measuring uncertainty: U_{1D} = 50 nm (k=2)
  - Full 3D measurement (-90º to +90º)
  - Product mass up to 32 kg
  - Air bearings for 3D scanning
  - Exchangeable probe with kinematic mount
    - 3D Probe system: Triskelion 3D ultra-precision tactile probe
    - Other possible probe systems: Optical probes, capacitive probes, oscillating fiber probes etc.

Isara 400 concept

- Abbe principle in 3D:
  - Measurement systems remain in line with measurement point
- X/Y movement of mirror table, Z movement of metrology frame



Isara 400 design concept



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Isara 400 design

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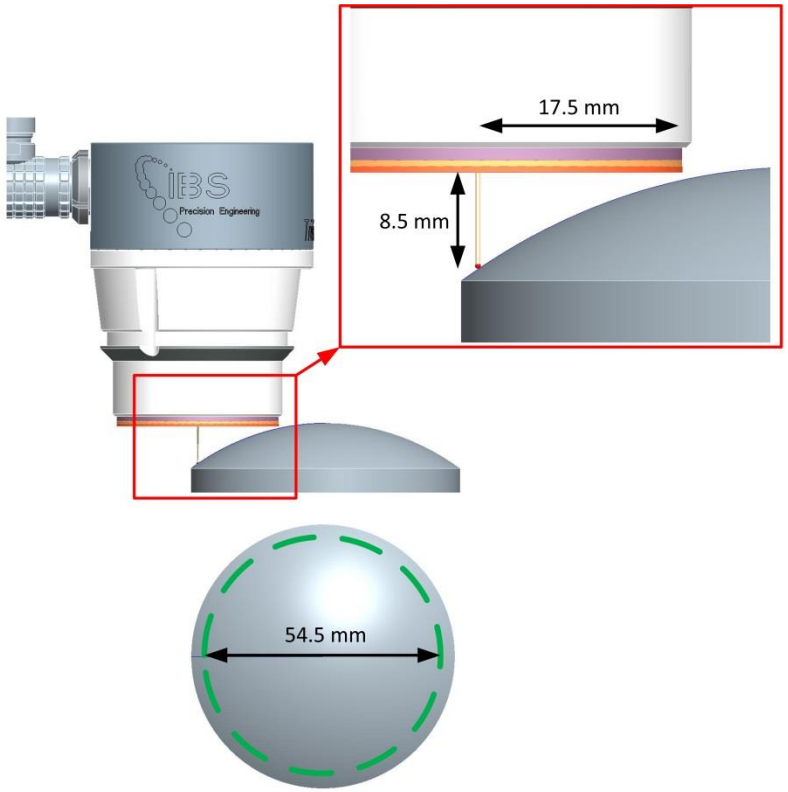
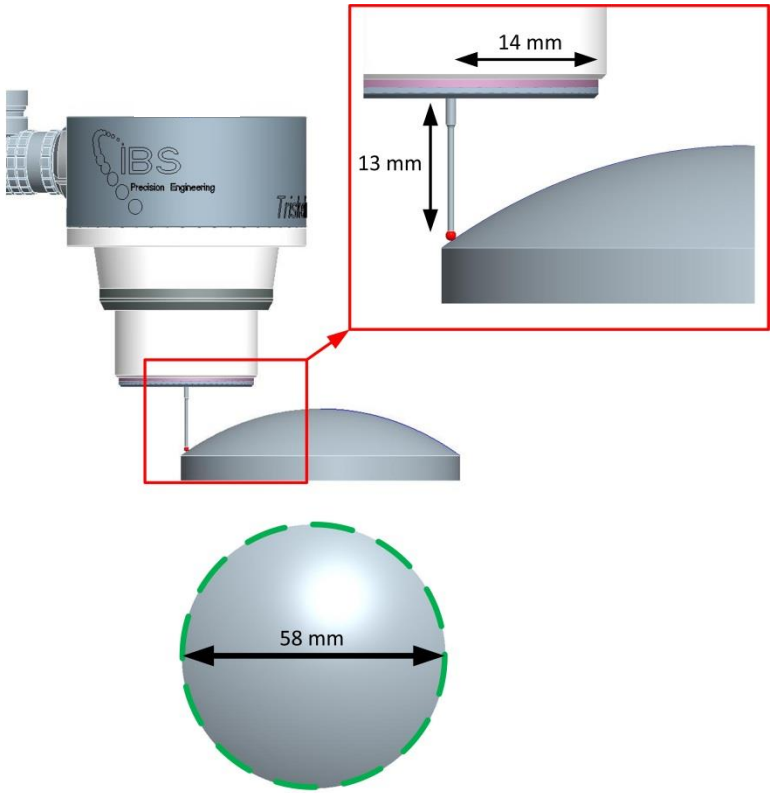
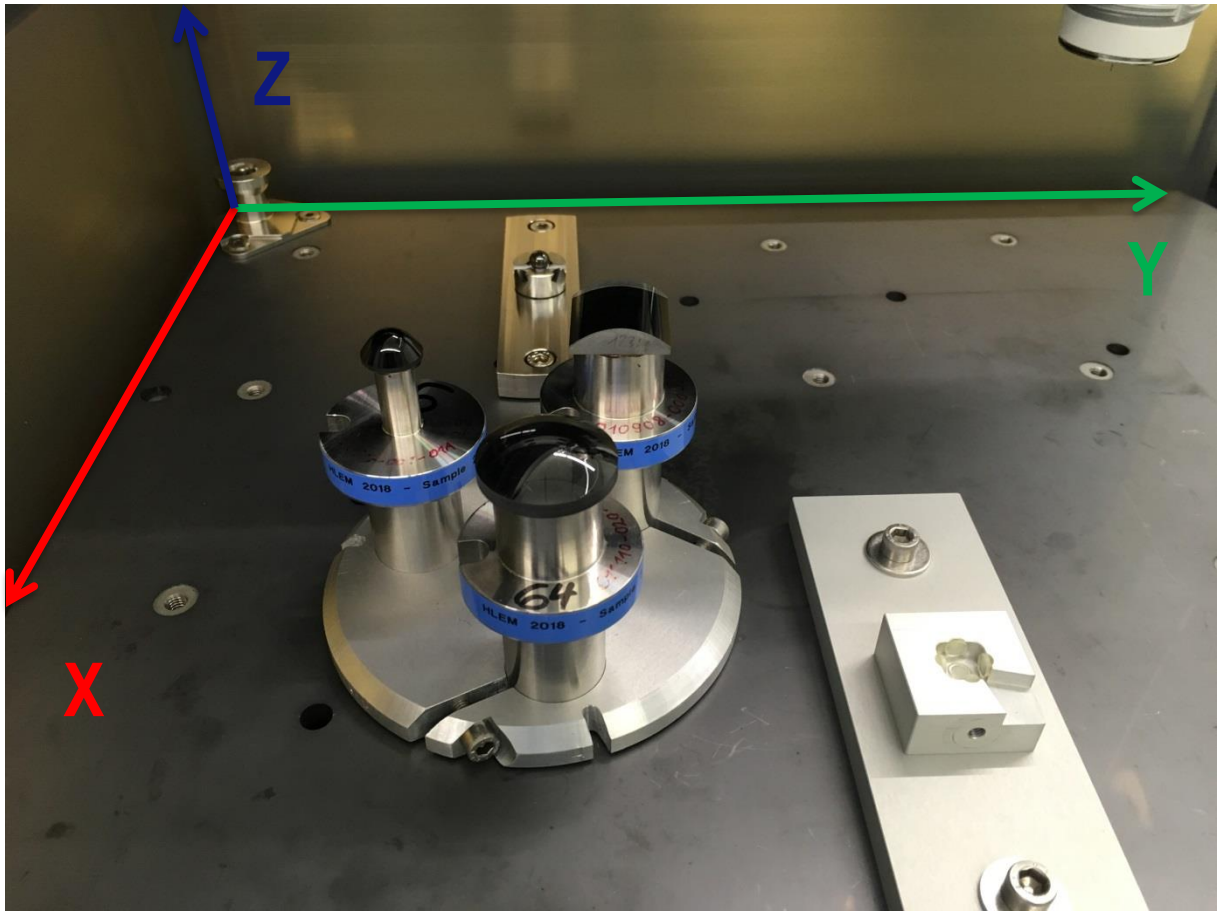
Measurement HLEM optics

- All measurements done with tactile probe measurements
- Slope limited by probe body





Measurement setup 2, 3, 4



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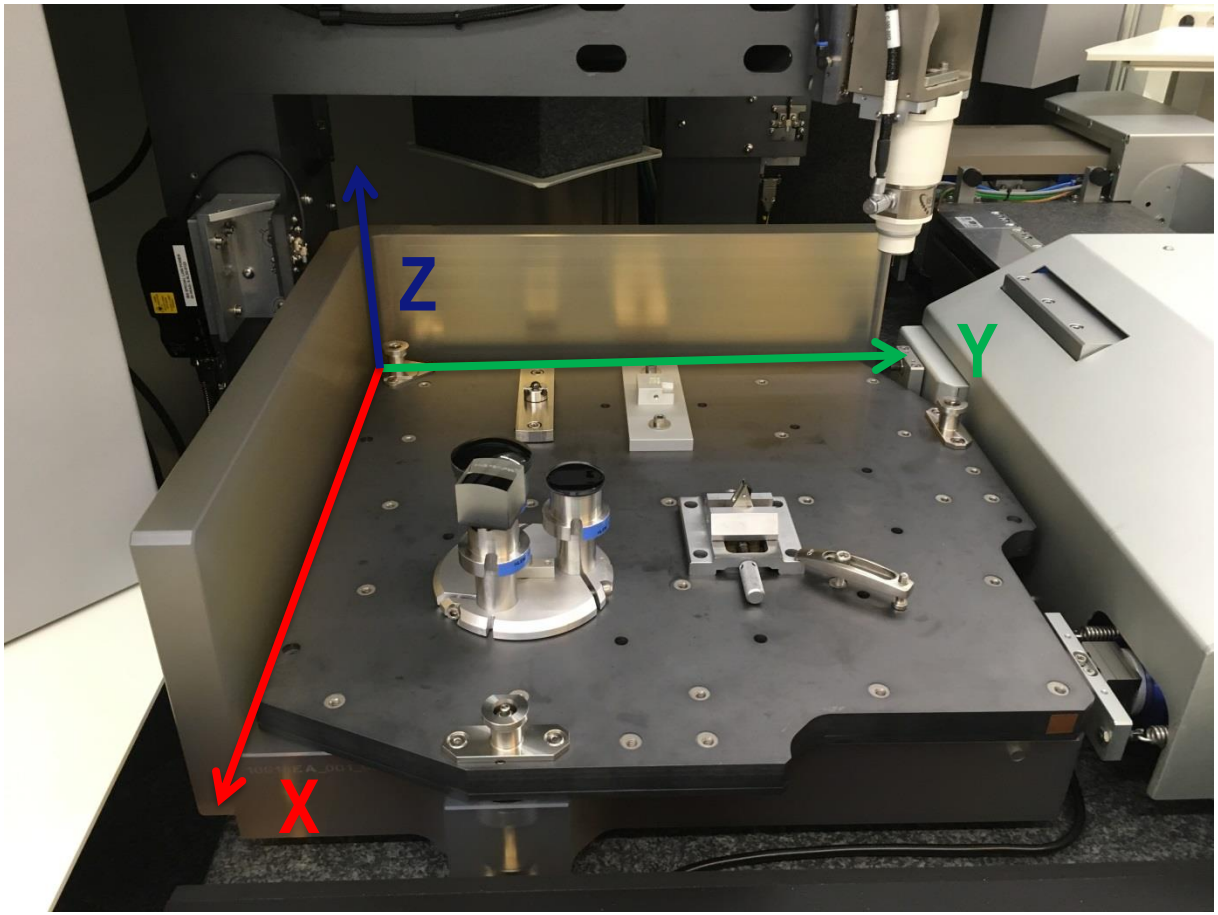
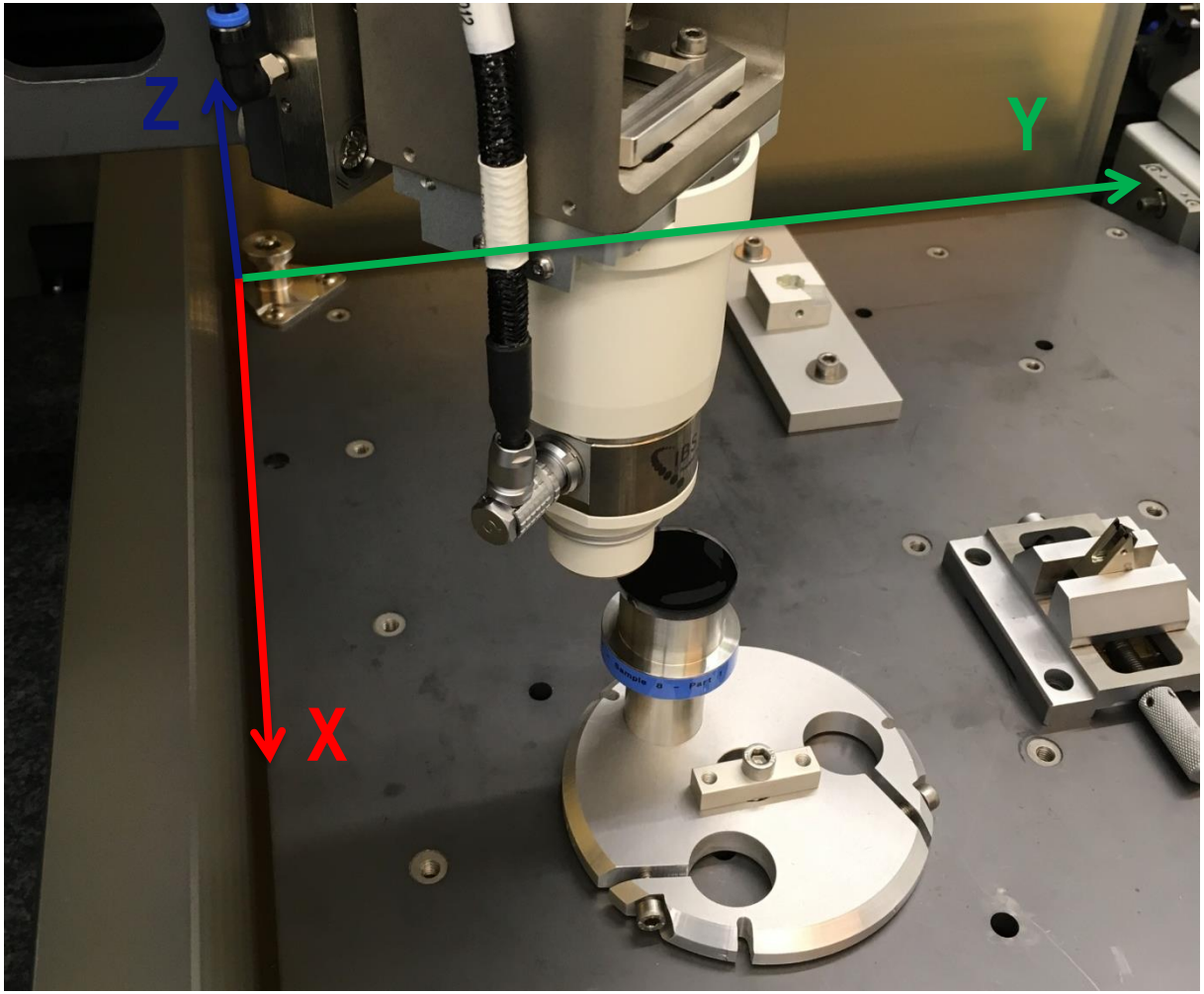
Measurement setup 5, 6, 7



Measurement setup 8



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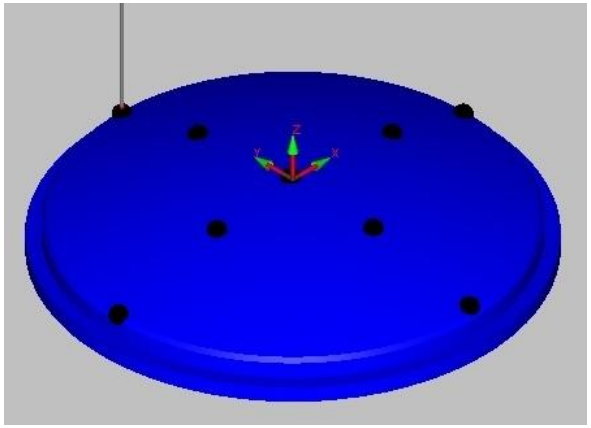
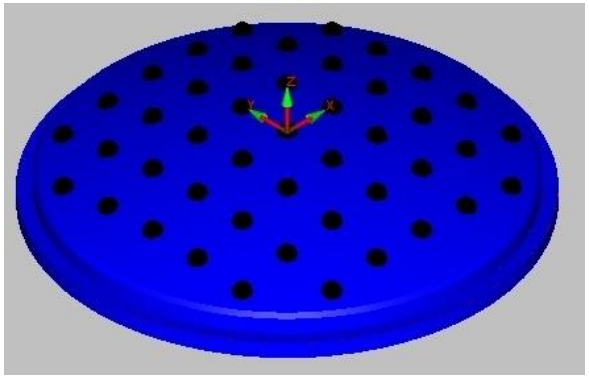
Measurement setup

- Alignment of part
  - Step 1: manual probing of 9 points
  - Calculate best fit alignment (x,y,z,Rx,Ry,(Rz))
  - Only manual action needed
  - Step 2: perform automated coarse grid
  - Recalculate best fit alignment
- Very quick on-machine alignment
  - Setup time: ~30 min
  - Automated alignment of more complex and free-form optics equally simple





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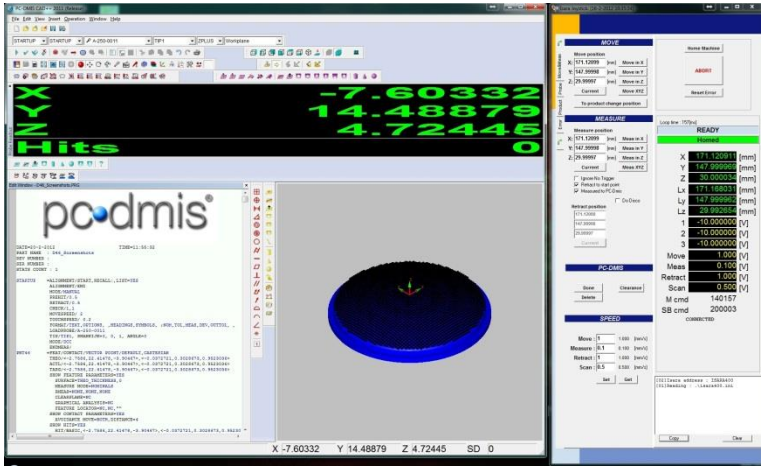
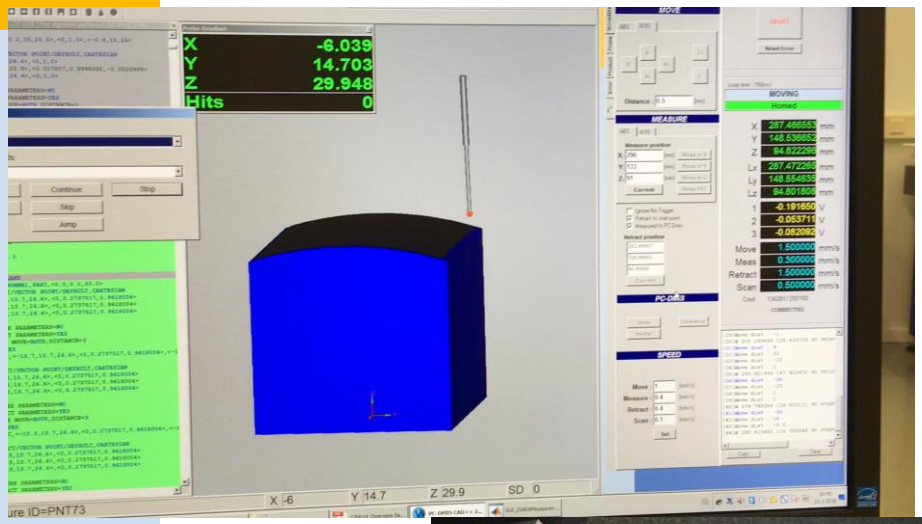
Measurement setup

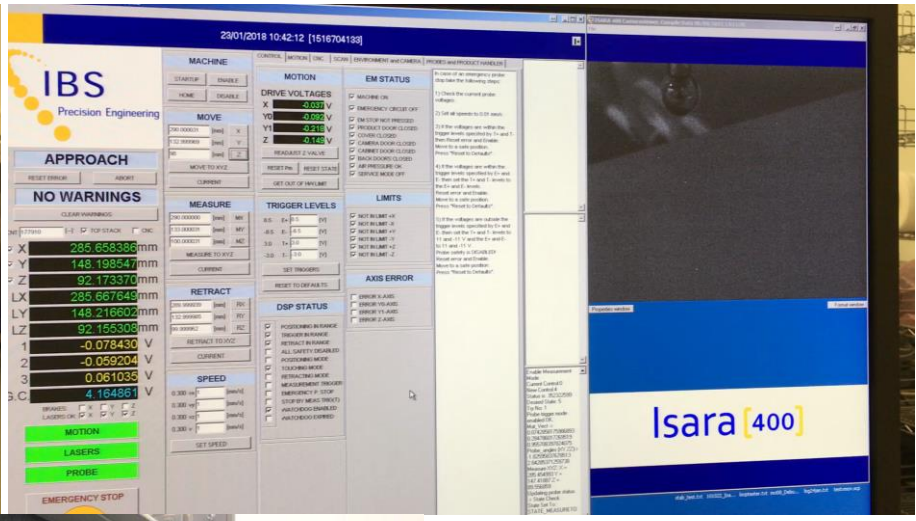
- Grid measurement of part
  - Perform fine grid of measurement points
  - Recalculate best fit alignment and visualize form deviations

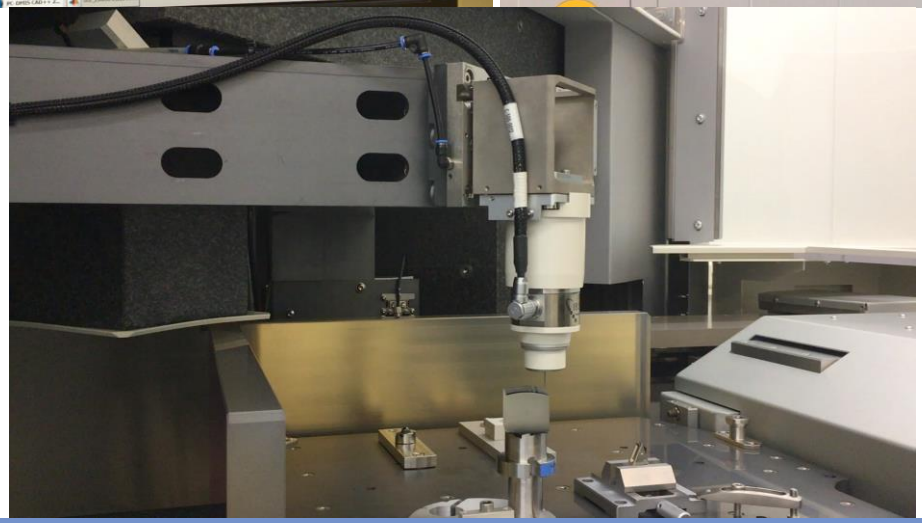


- Scan measurements
  - Not performed (due to time limitation)

HLEM Measurement







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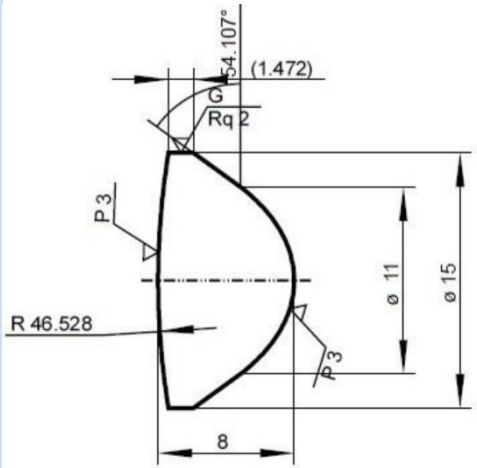
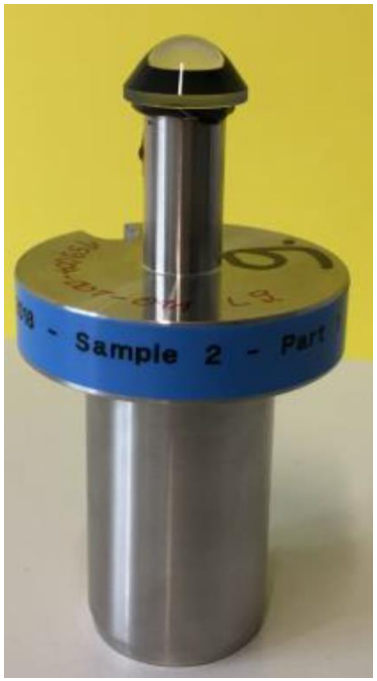
Measurement of sample 2

Small Asphere





$$z(h)=\frac{h^2}{R\left(1+\sqrt{1-(1+k)\frac{h^2}{R^2}}\right)}+\sum_{i=2}^{n} A_{2i}h^{2i}$$

R	=	5.446
k	=	-0.17
A_4	=	-0.00029559792
A_6	=	-6.3943709e-006
A_8	=	-3.025556e-007
A_{10}	=	1.409072e-008
A_{12}	=	-1.2183175e-009
A_{14}	=	4.0114145e-011
A_{16}	=	-6.9463522e-013

h	z(h)
0.0	-0.000000
1.0	-0.092160
2.0	-0.372932
3.0	-0.855888
4.0	-1.565864
5.0	-2.541486

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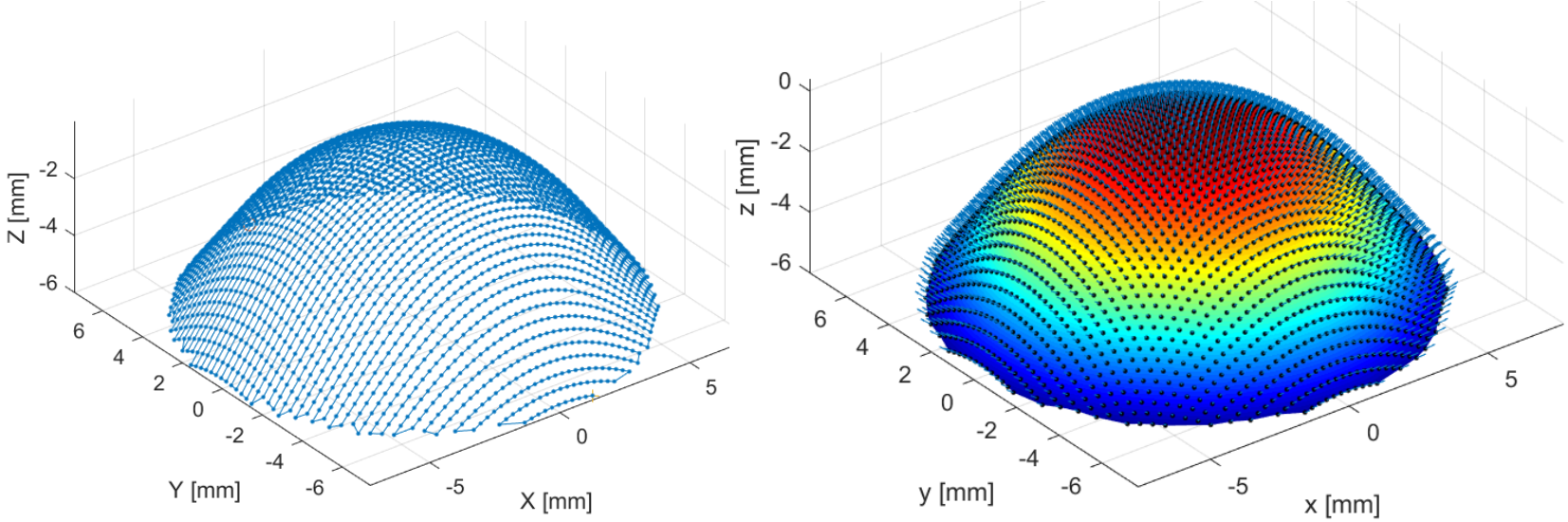
Measurement of sample 2

- Grid spacing: 0.26 mm
- Number of points: 2682
- Measurement time: 9 hours
- Measured diameter: 14.7 mm
- Probe used: Triskelion A-250-0011 (Ø 500 µm Ruby tip)



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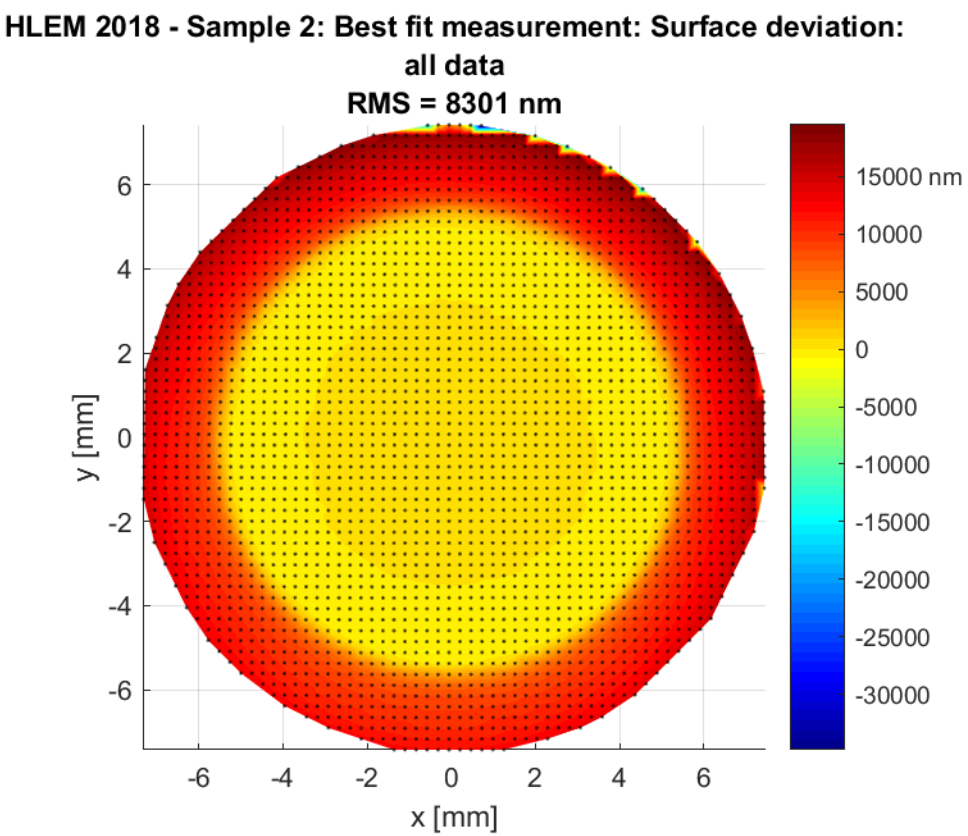
Measurement results: sample 2

- Form deviation w.r.t. theoretical design



- Best fit optimisation performed to determine position and orientation
- Large deviation on sloped outer ring

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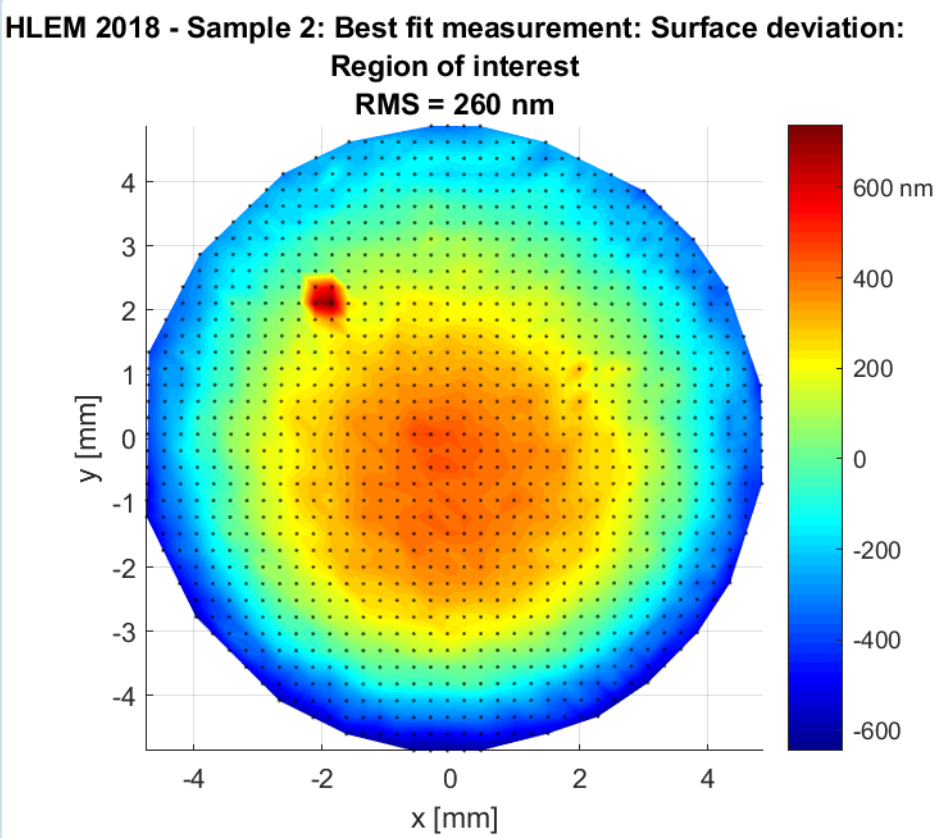
Measurement results: sample 2

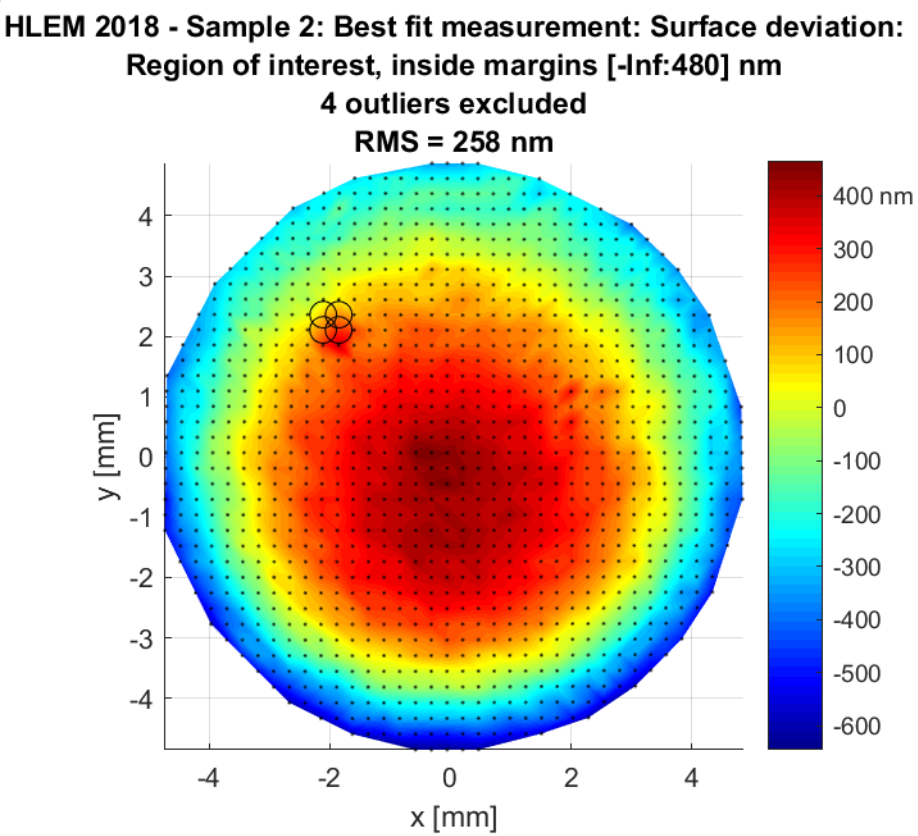
- Form deviation w.r.t. theoretical design



- Best fit optimisation performed to determine position and orientation
- Focus on inner part (Ø11 mm)
- Noticeable contamination

Measurement results: sample 2

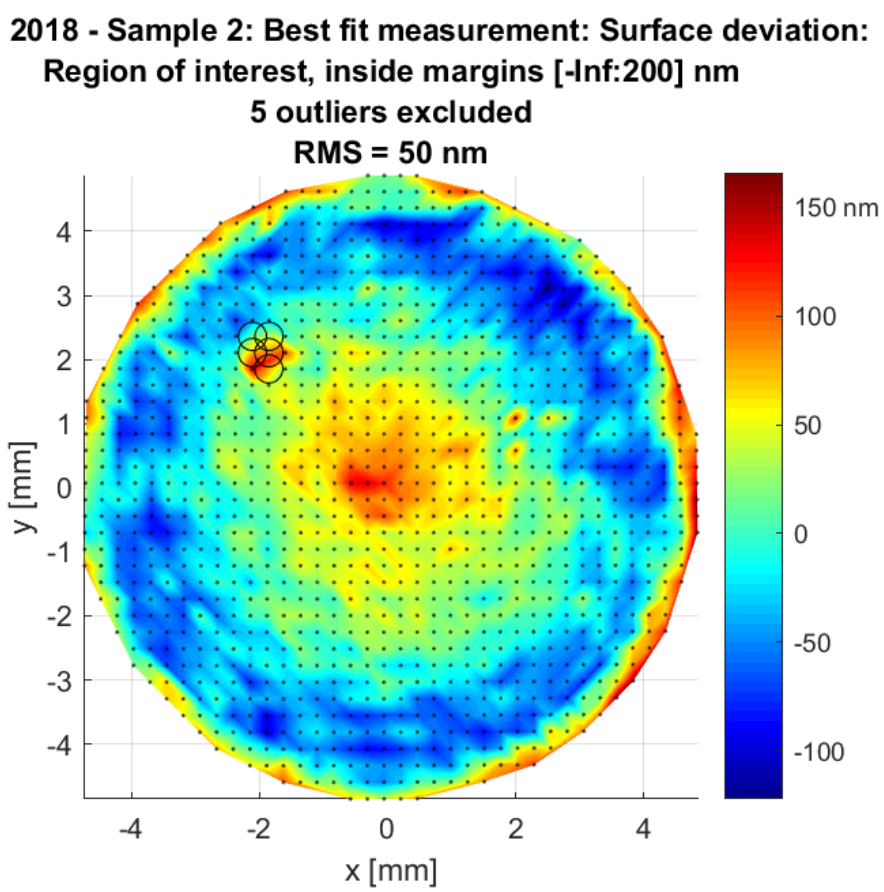
- Form deviation w.r.t. theoretical design



- Best fit optimisation performed to determine position and orientation
- Focus on inner part
- Outliers (due to contamination) excluded (circles)

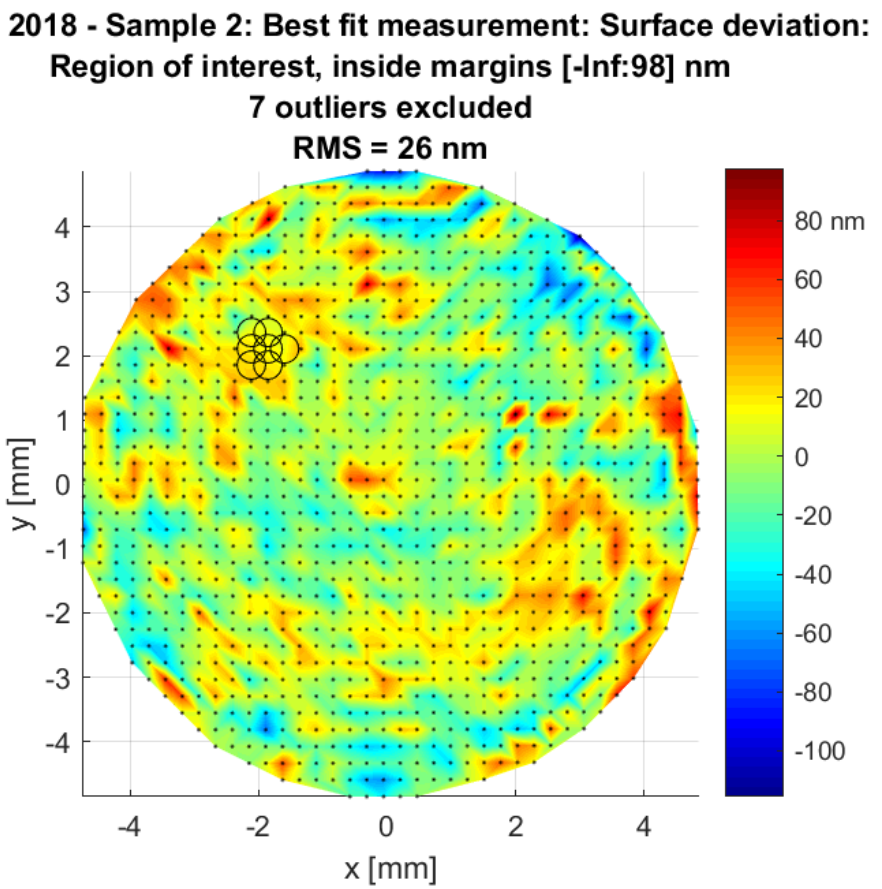
Measurement results: sample 2

- Deviation from theoretical design, with variable radius
  - Best fit optimisation: position, orientation and radius R (from aspherical formula)
  - ΔR = -1.014 µm (-0.019%)



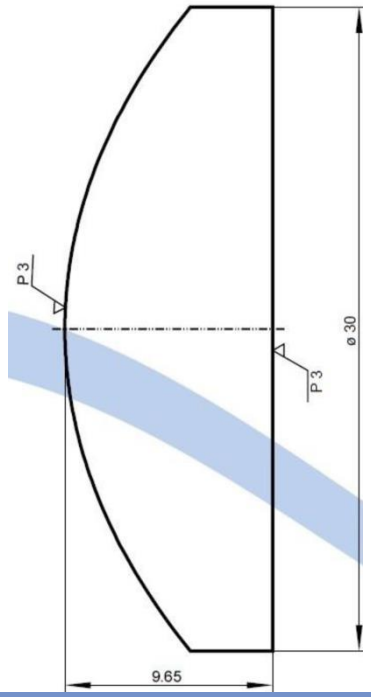
Measurement results: sample 2

- Deviation from theoretical design, with variable radius and k
  - Best fit optimisation: position, orientation and radius R and k (from aspherical formula)
  - ΔR = -1.825 µm (-0.034%)
  - Δk = -0.000595 (-0.350%)



Measurement of sample 3

Asphere



$$z(h)=\frac{h^2}{R\left(1+\sqrt{1-(1+k)\frac{h^2}{R^2}}\right)}+\sum_{i=2}^{n} A_{2i}h^{2i}$$

R	=	20.20 ±0.05%
k	=	-1
A_4	=	5.4144542e-006
A_6	=	-8.0413315e-010
A_8	=	-2.9871189e-012
A_{10}	=	-1.4917927e-015
A_{12}	=	1.3777317e-018
A_{14}	=	4.4258023e-021
A_{16}	=	-3.4927668e-024

h	z(h)
0.0	-0.000000
2.0	-0.099096
4.0	-0.397422
6.0	-0.898064
8.0	-1.606074
10.0	-2.528276
12.0	-3.672870
14.0	-5.048712
15.0	-5.826023

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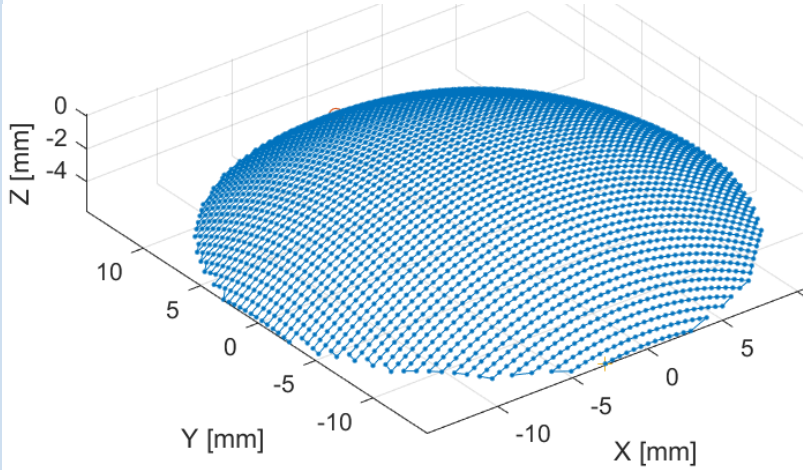
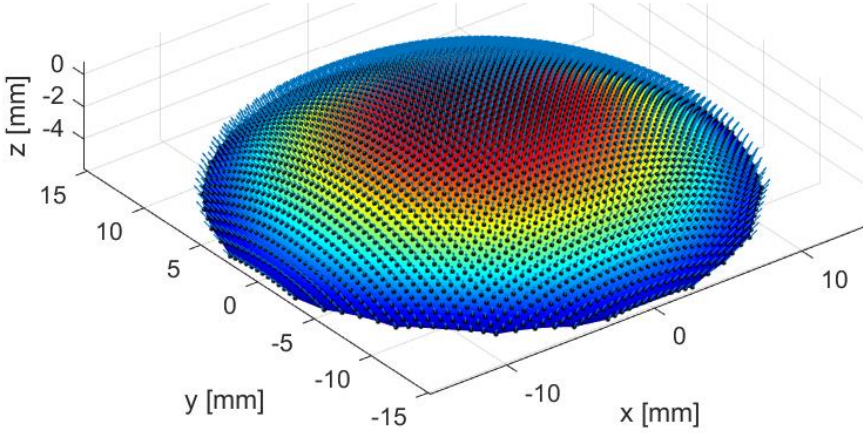
Measurement of sample 3

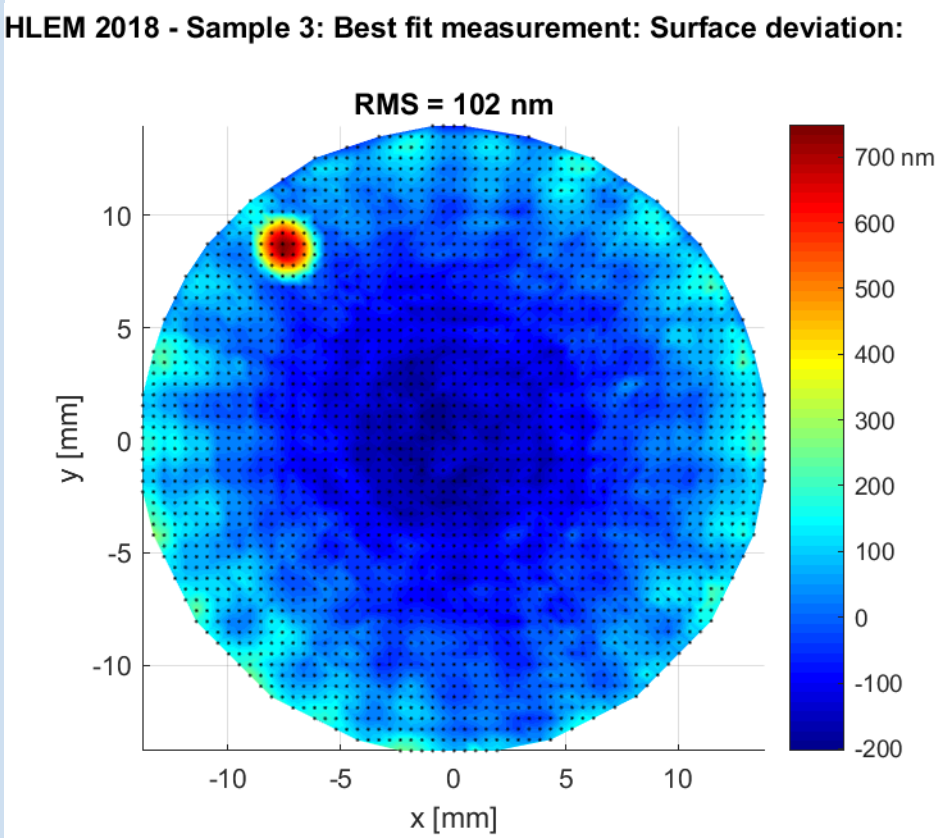
- Grid spacing: 0.48 mm
- Number of points: 3125
- Measurement time: 9 hours
- Measured diameter: 29.5 mm
- Probe used: Triskelion A-250-0011 (Ø 500 µm Ruby tip)





Measurement results: sample 3

- Form deviation w.r.t. theoretical design



- Best fit optimisation performed to determine position and orientation
- Noticeable contamination (same direction, but at larger radius due to less curvature ➔ contamination located on probe tip)

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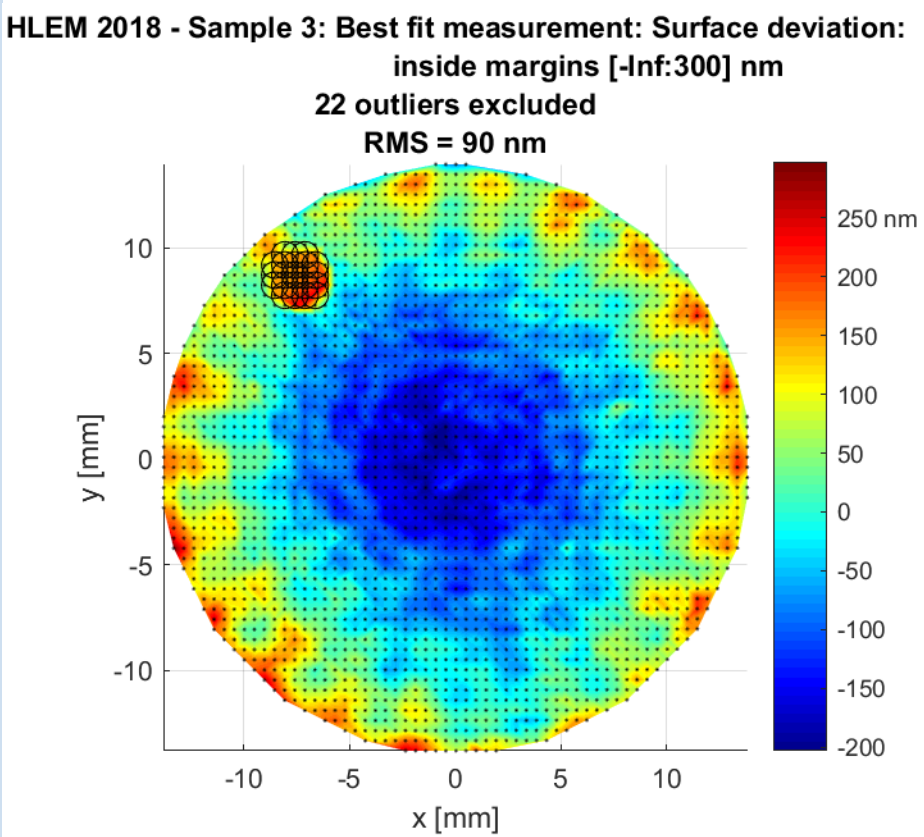
Measurement results: sample 3

- Form deviation w.r.t. theoretical design



- Best fit optimisation performed to determine position and orientation
- Outliers (due to contamination) excluded (circles)

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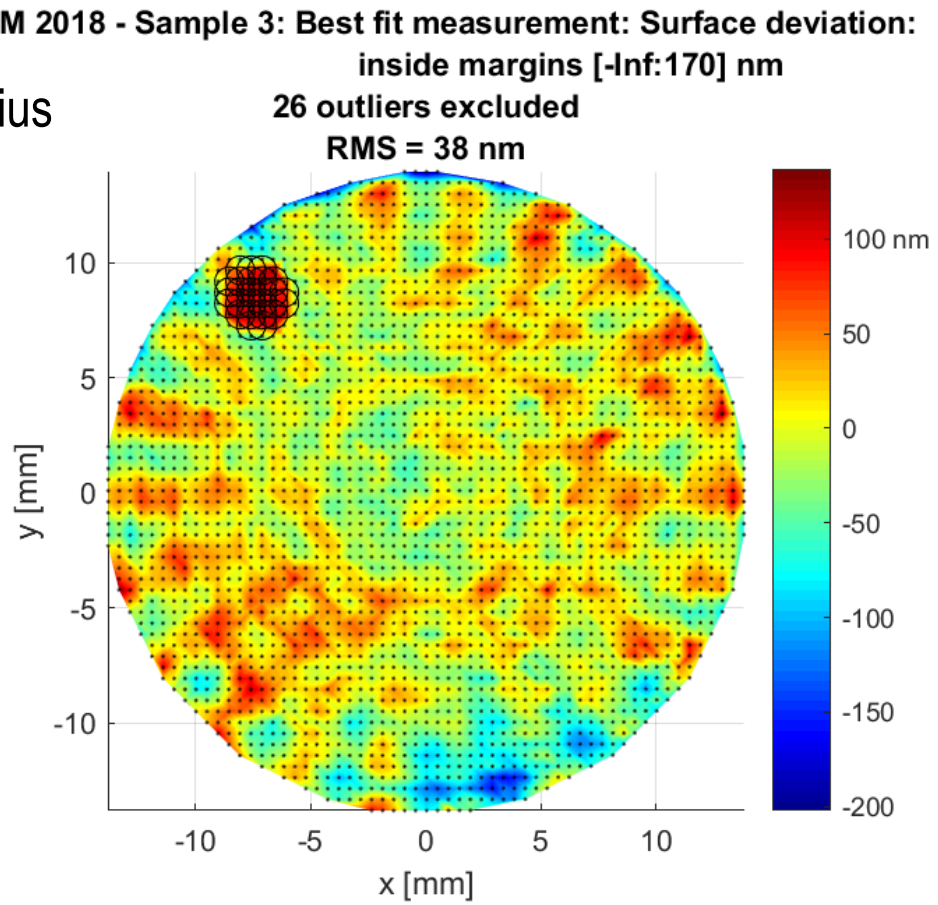
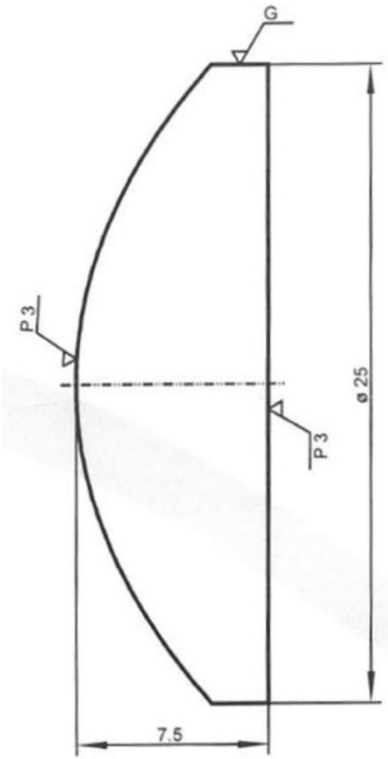
Measurement results: sample 3

- Deviation from theoretical design, with variable radius
  - Best fit optimisation: position, orientation and radius R (from aspherical formula)
  - ΔR = 1.232 µm (0.006%)



Measurement of sample 4

Non circular cylinder
"Aspheric cylinder"



$$z(h)=\frac{h^2}{R\left(1+\sqrt{1-(1+k)\frac{h^2}{R^2}}\right)}+\sum_{i=2}^{n} A_{2i}h^{2i}$$

R	=	15.538 $^{+0.5\%}_{-0\%}$
k	=	-1
A_4	=	1.1926075e-005
A_6	=	-2.9323497e-009
A_8	=	-1.8718889e-011
A_{10}	=	-1.7009961e-014
A_{12}	=	3.5481542e-017
A_{14}	=	6.5241296e-020

h	z(h)
0.0	-0.000000
2.0	-0.128907
4.0	-0.517907
6.0	-1.173737
8.0	-2.107218
10.0	-3.332246
12.0	-4.863642
12.5	-5.295897

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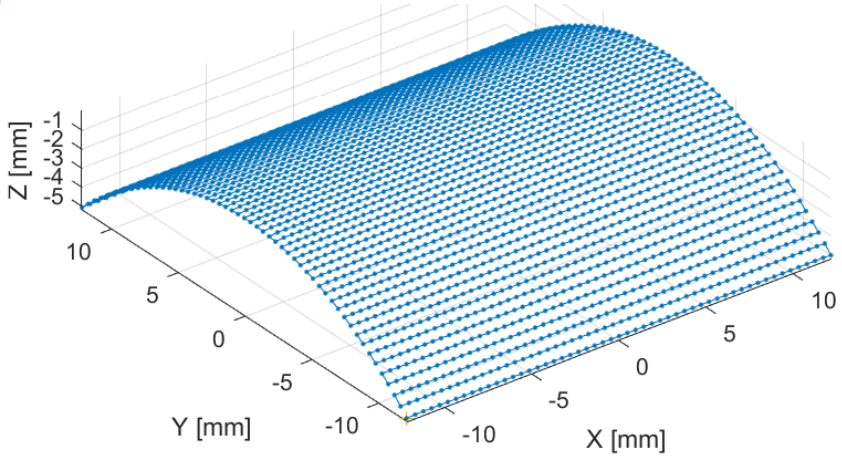
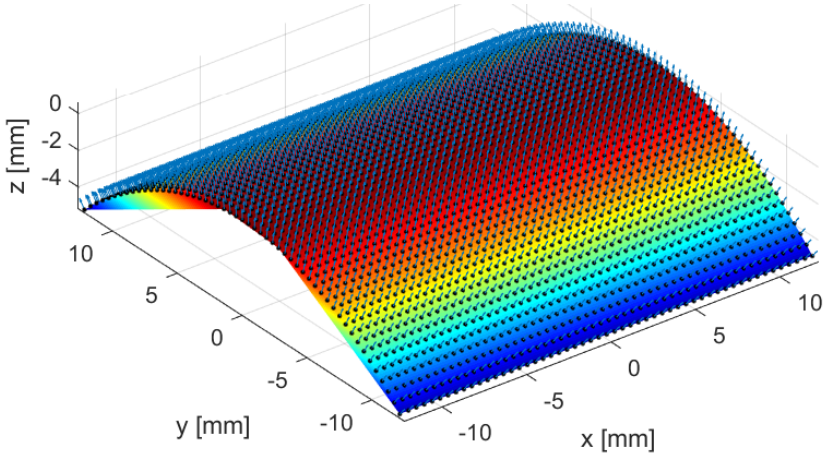
Measurement of sample 4

- Grid spacing: 0.47 mm
- Number of points: 2809
- Measurement time: 8 hours
- Measured area: 24.4 mm x 24.3 mm
- Probe used: Triskelion A-250-0011 (Ø 500 µm Ruby tip)





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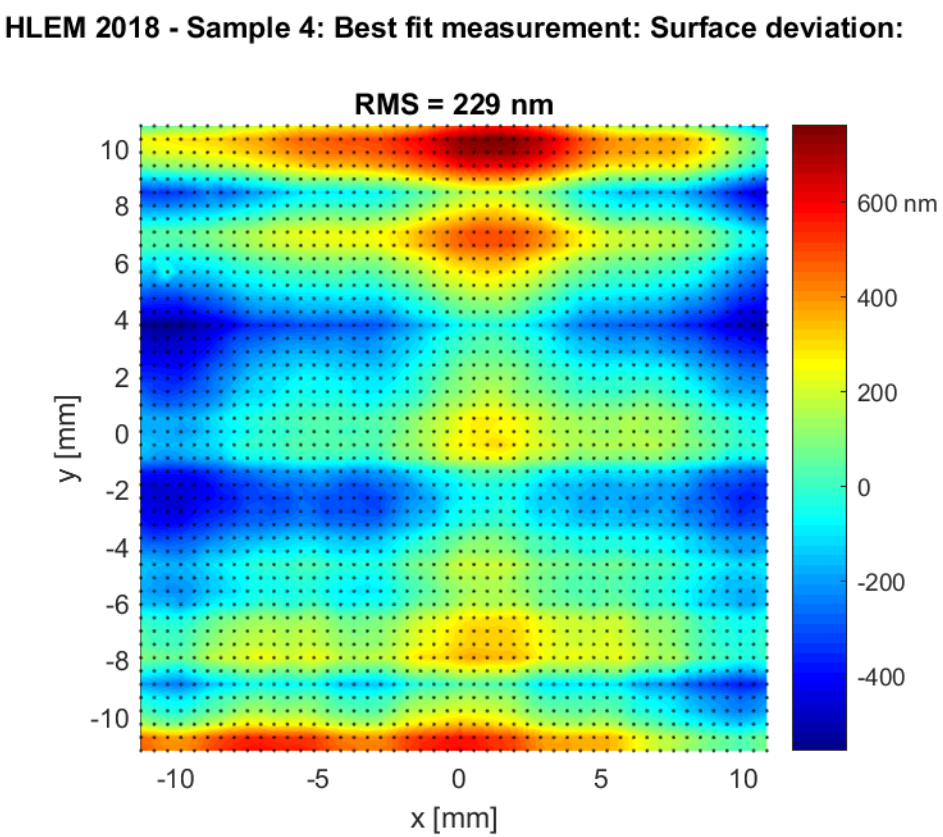
Measurement results: sample 4

- Form deviation w.r.t. theoretical design



- Best fit optimisation performed to determine position and orientation
- Not affected by contamination on probe tip due to curvature direction

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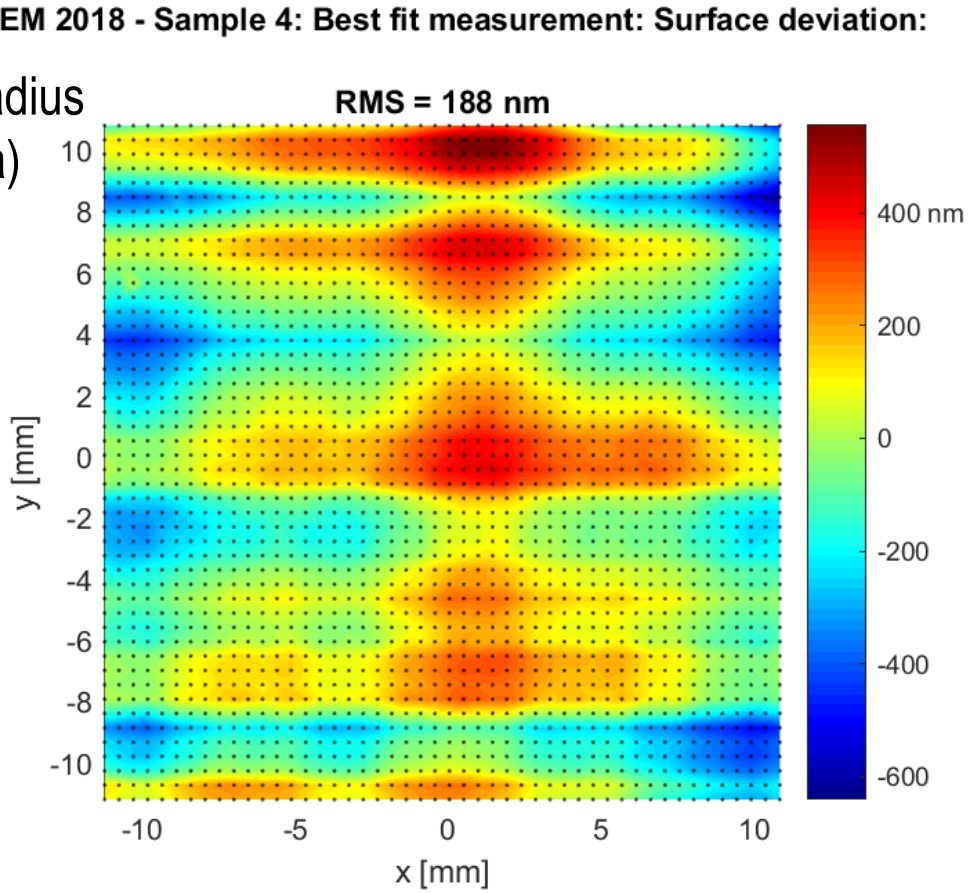
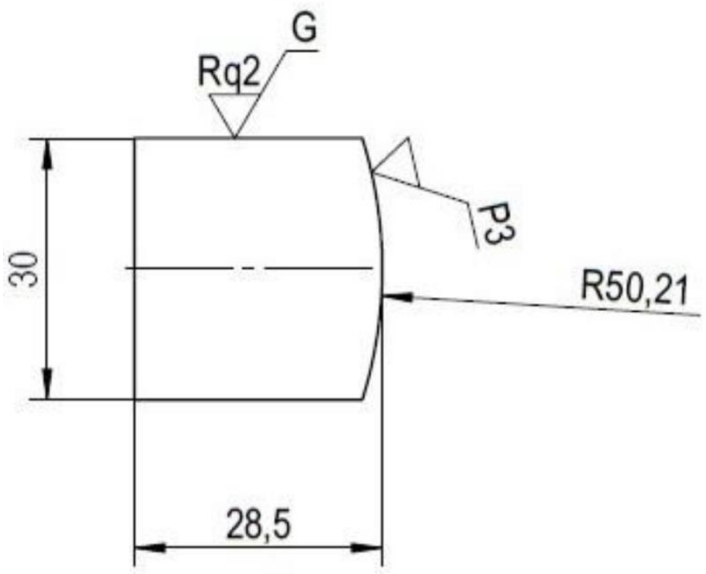
Measurement results: sample 4

- Deviation from theoretical design, with variable radius
  - Best fit optimisation: position, orientation and radius R (from aspherical formula)
  - ΔR = 1.643 µm (0.011%)



Measurement of sample 5

Cylinder Optic



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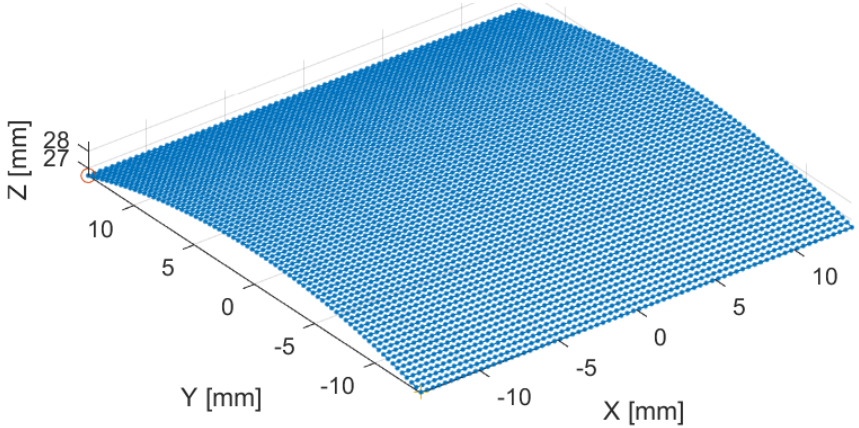
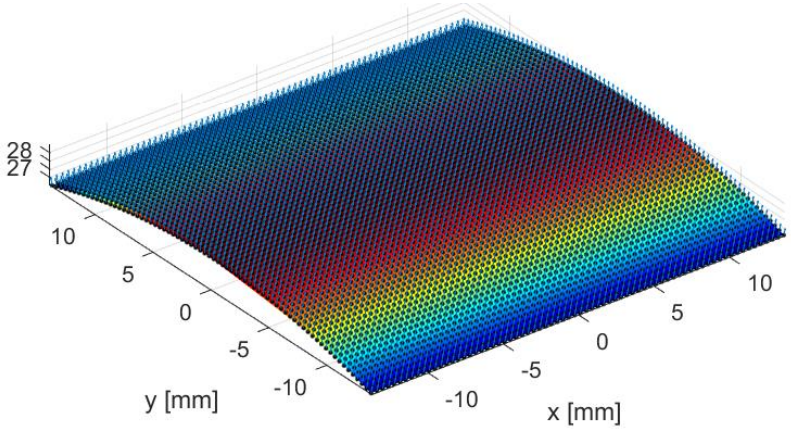
Measurement of sample 5

- Grid spacing: 0.39 mm
- Number of points: 5184
- Measurement time: 17.5 hours
- Measured area: 27.4 mm x 27.5 mm
- Probe used: Triskelion C-500-0012 (Ø 1000 µm Ruby tip)





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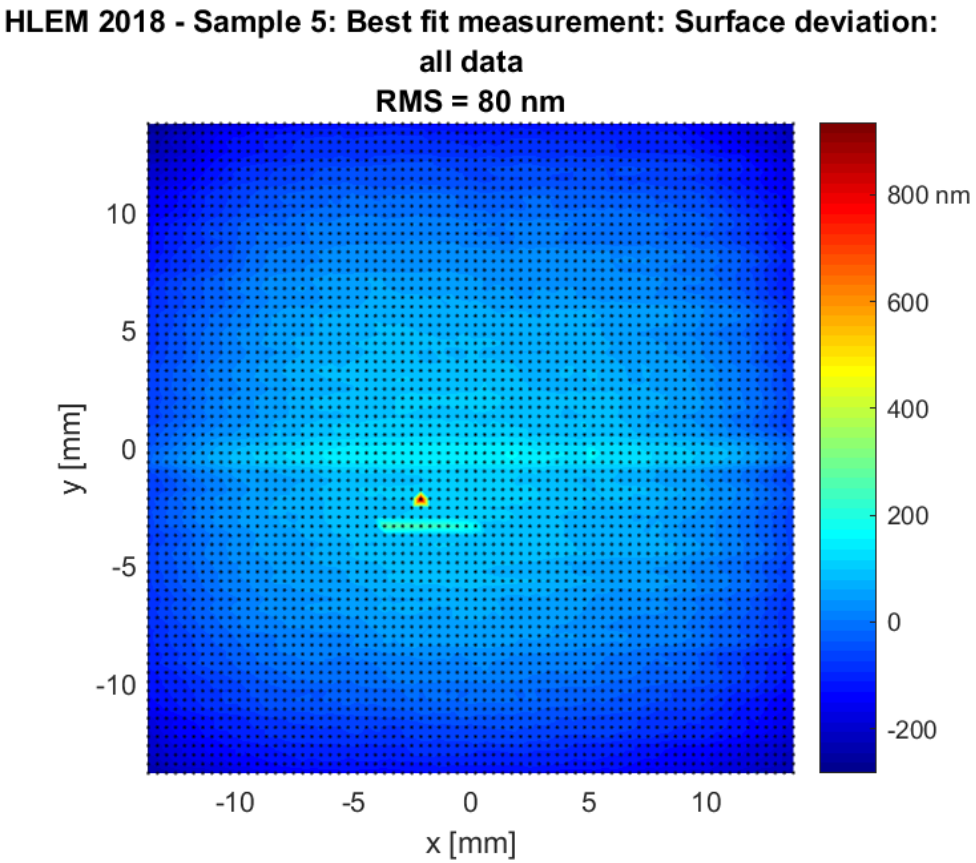
Measurement results: sample 5

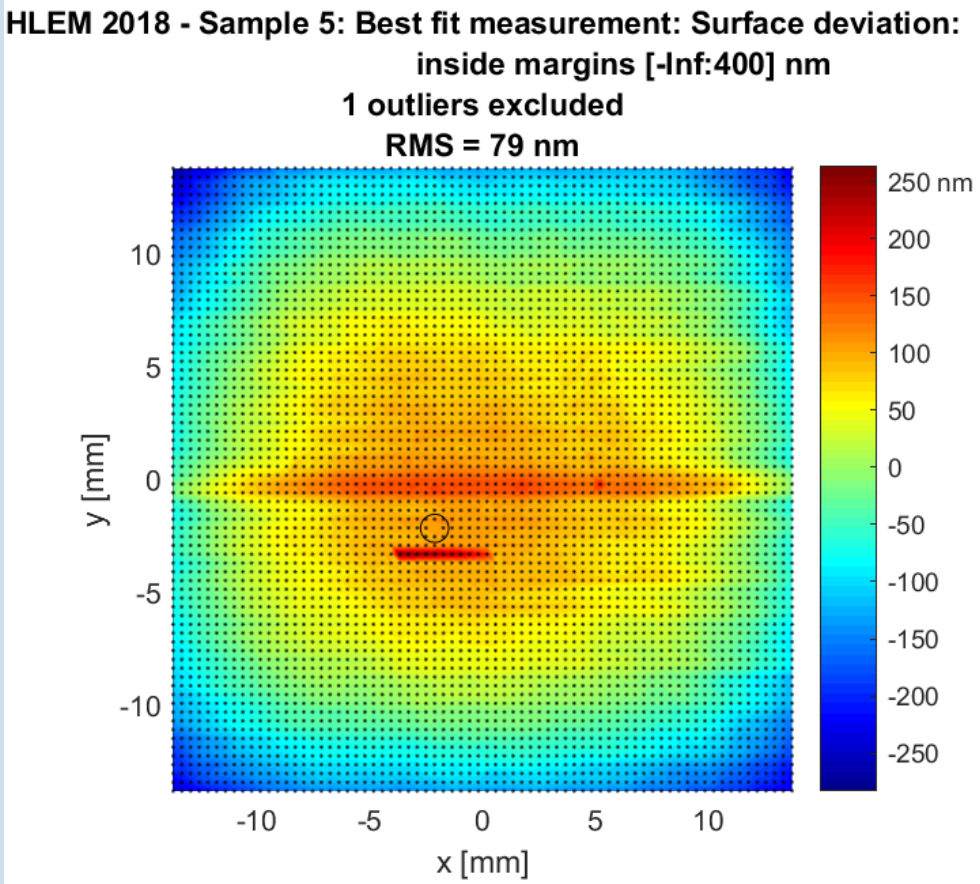
- Form deviation w.r.t. theoretical design



- Best fit optimisation performed to determine position and orientation
- Noticeable contamination

Measurement results: sample 5

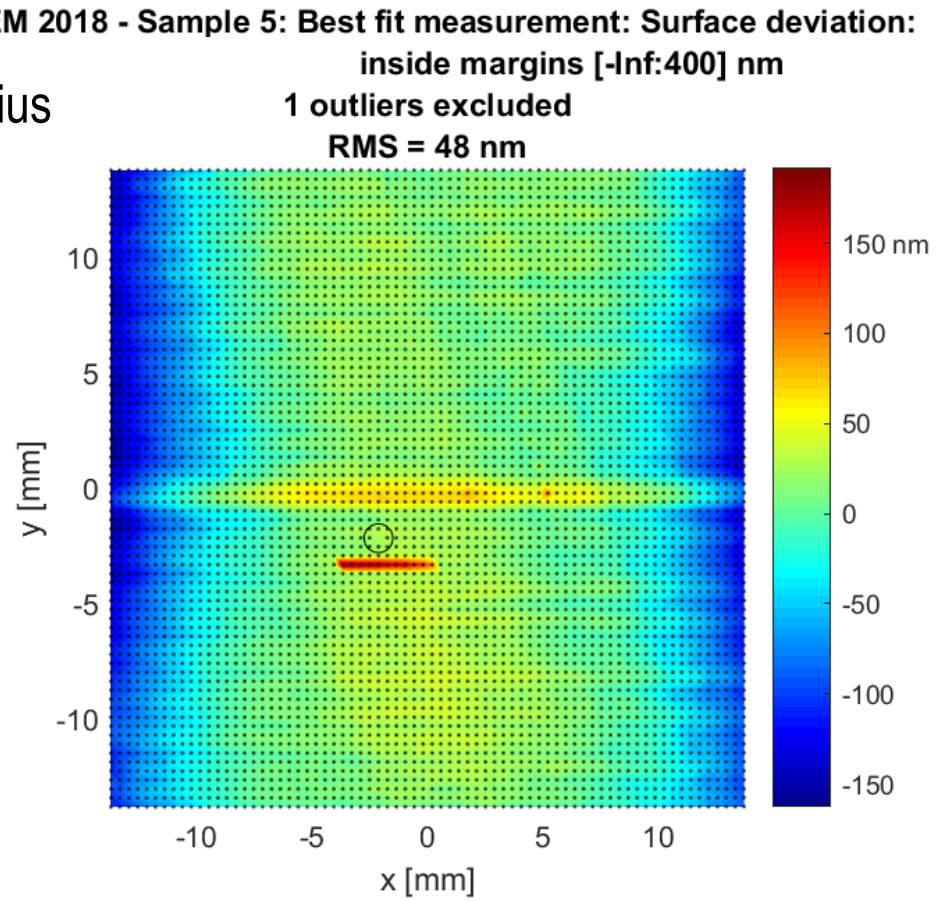
- Form deviation w.r.t. theoretical design



- Best fit optimisation performed to determine position and orientation
- Outlier (due to contamination) excluded (circle)

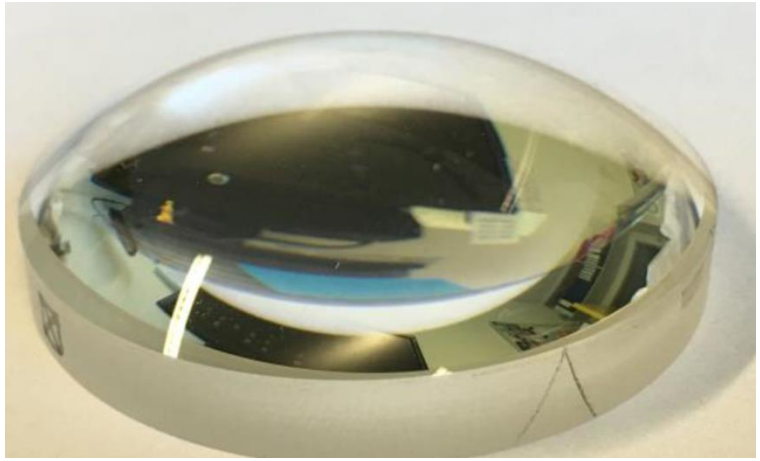
Measurement results: sample 5

- Deviation from theoretical design, with variable radius
  - Best fit optimisation: position, orientation and radius R (from aspherical formula)
  - ΔR = -5.462 µm (-0.011%)



Measurement of sample 6

- Convex toroid
- Rv = 40 mm
- Rh = 42 mm
- Diameter = 50 mm

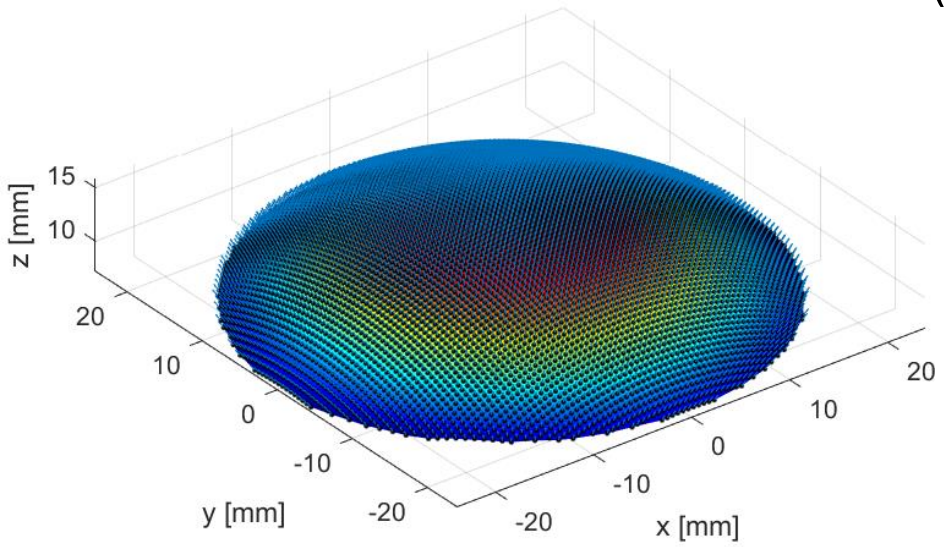


- Assumed formula:

$$z(x,y) = \sqrt{\left(\sqrt{{R_h}^2 - x^2} + R_v - R_h\right)^2 - y^2} - R_v$$

Measurement of sample 6

- Grid spacing: 0.53 mm
- Number of points: 6286
- Measurement time: 22 hours
- Measured diameter: 47 mm
- Probe used: Triskelion C-500-0012 (Ø 1000 µm Ruby tip)



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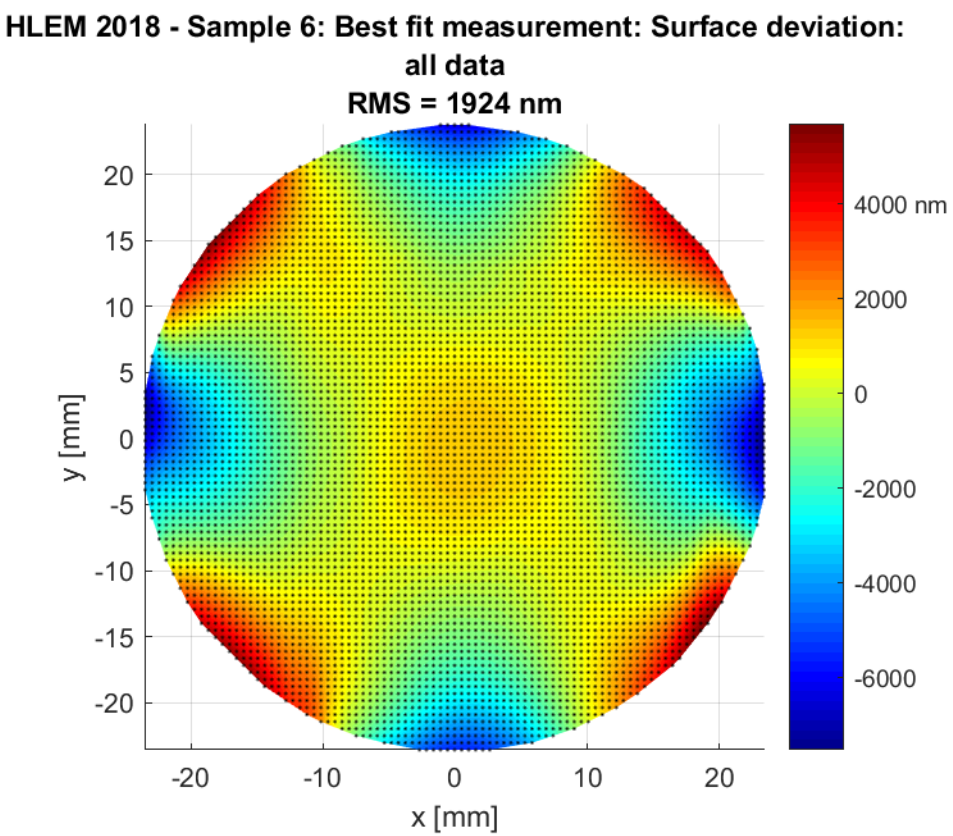
Measurement results: sample 6

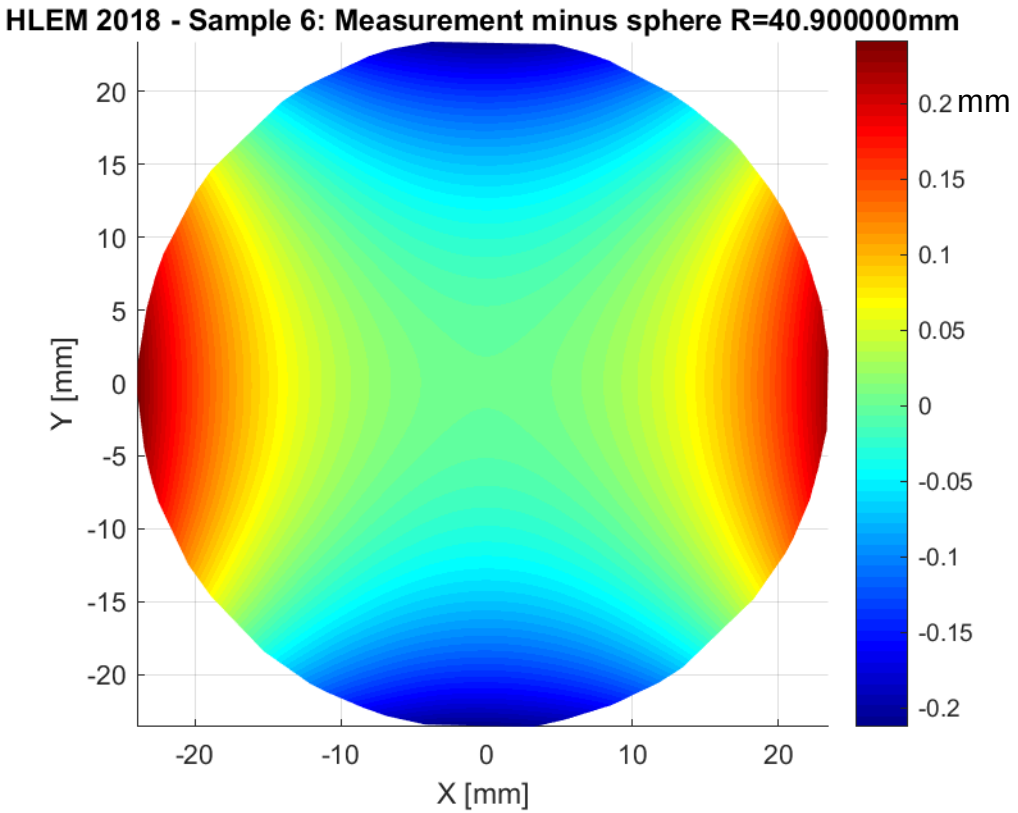
- Form deviation w.r.t. theoretical design



- Best fit optimisation performed to determine position and orientation
- Large deviation from toroid

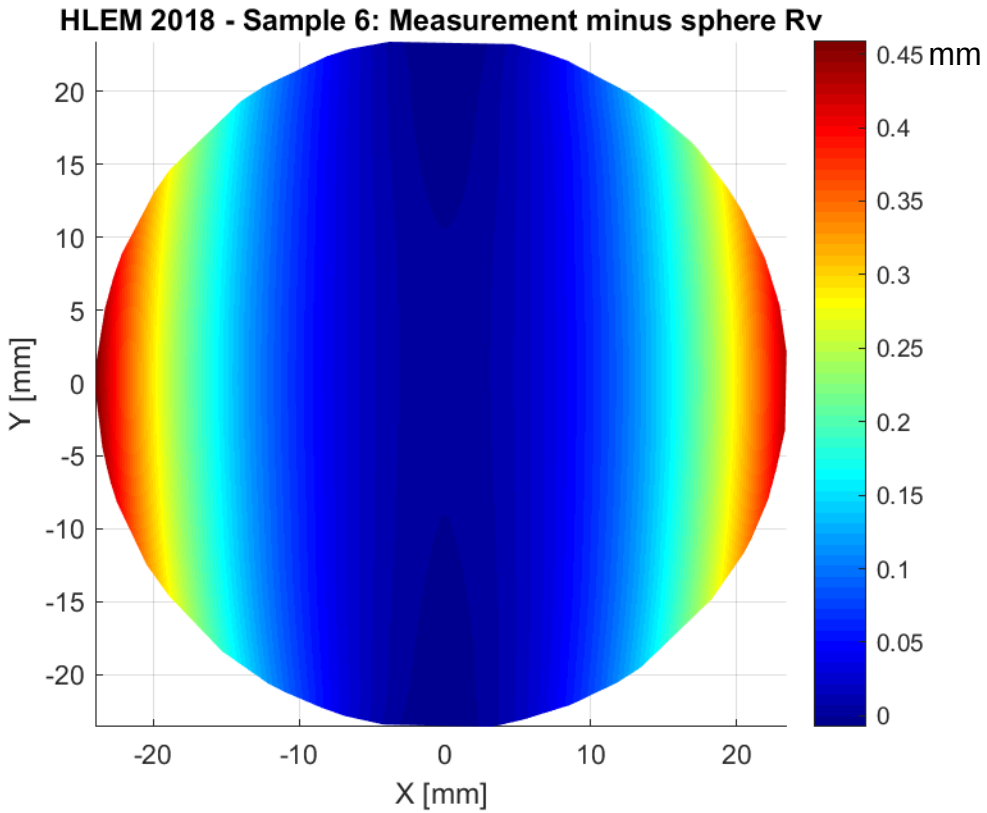
Measurement results: sample 6

- Minus sphere of R=40.9 mm



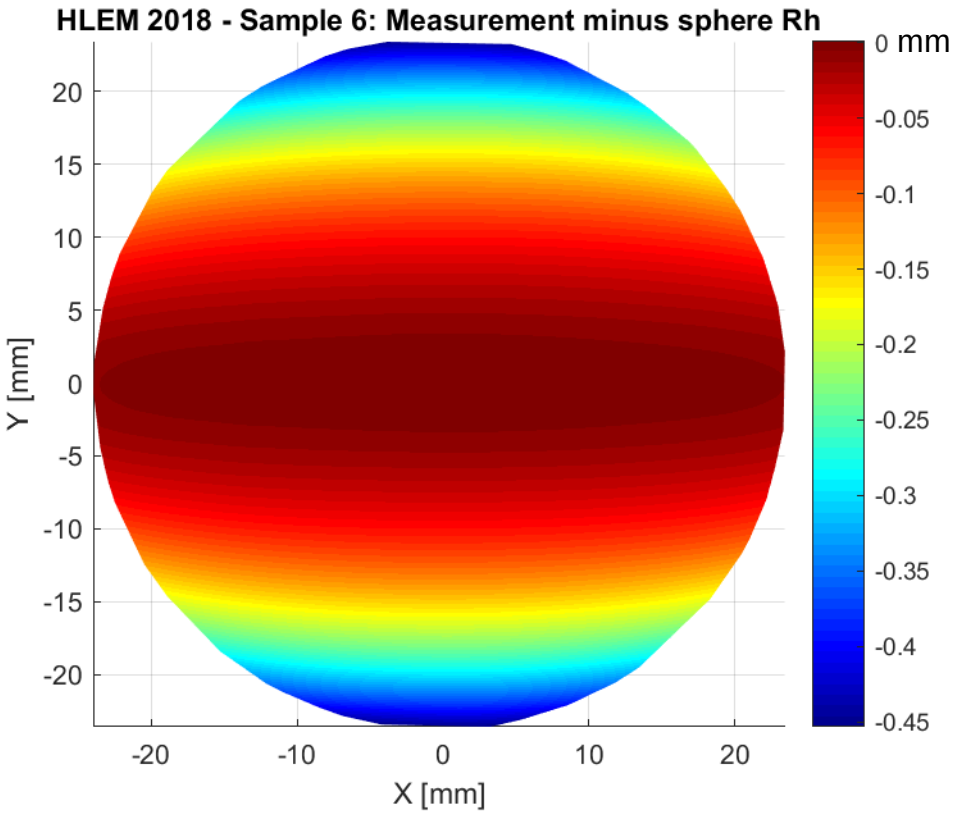
Measurement results: sample 6

- Minus sphere of Rv



Measurement results: sample 6

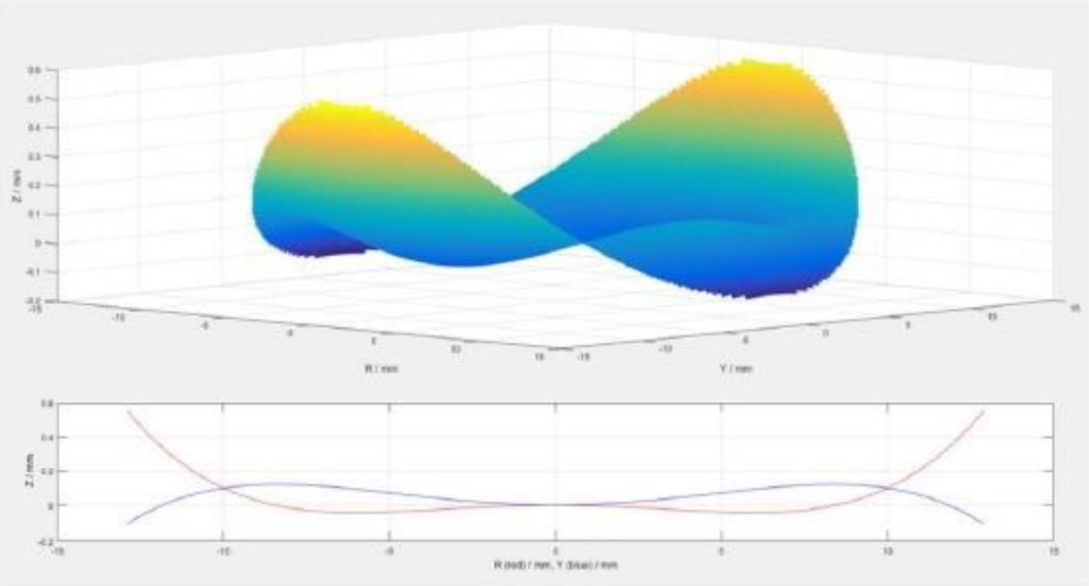
- Minus sphere of Rh

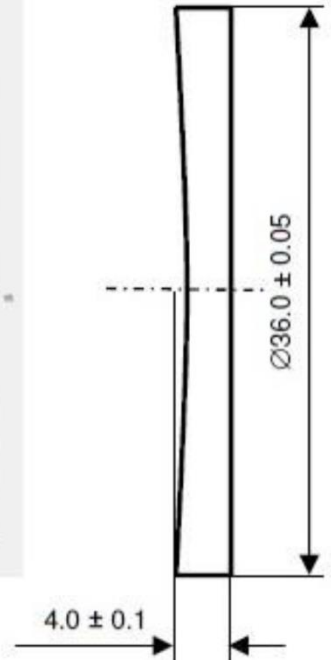


Measurement of sample 7

4th order polynomial freeform
“wild curvature”

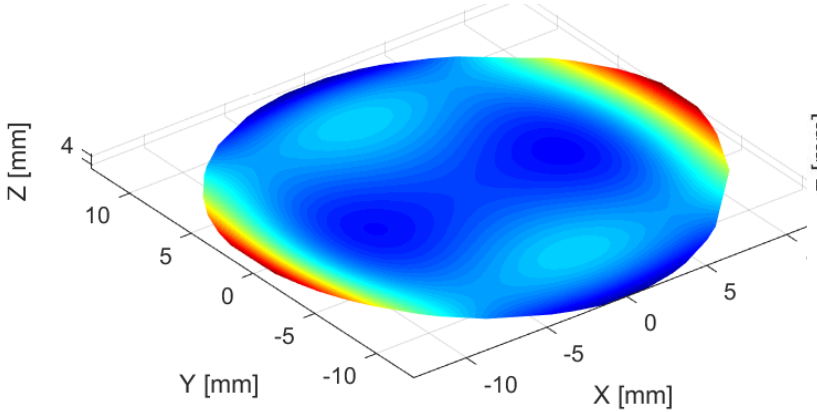
1) $H=Ax^2+By^2+Cx^4+Dy^4$

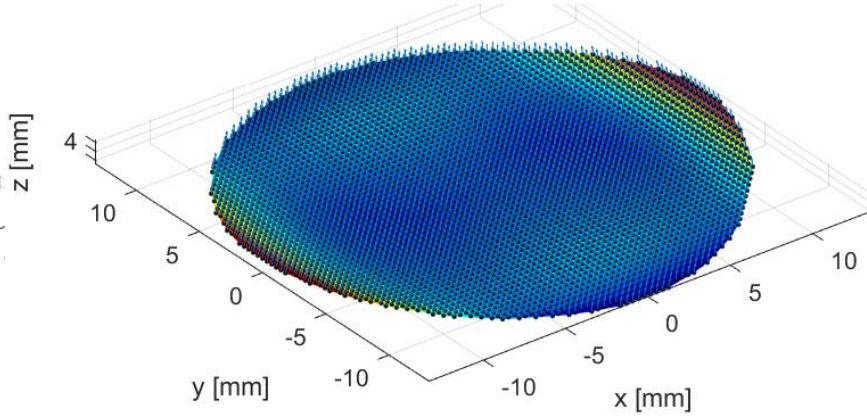




Measurement of sample 7

- Grid spacing: 0.37 mm
- Number of points: 4106
- Measurement time: 14 hours
- Measured diameter: 26.2 mm
- Probe used: Triskelion C-500-0012 (Ø 1000 µm Ruby tip)





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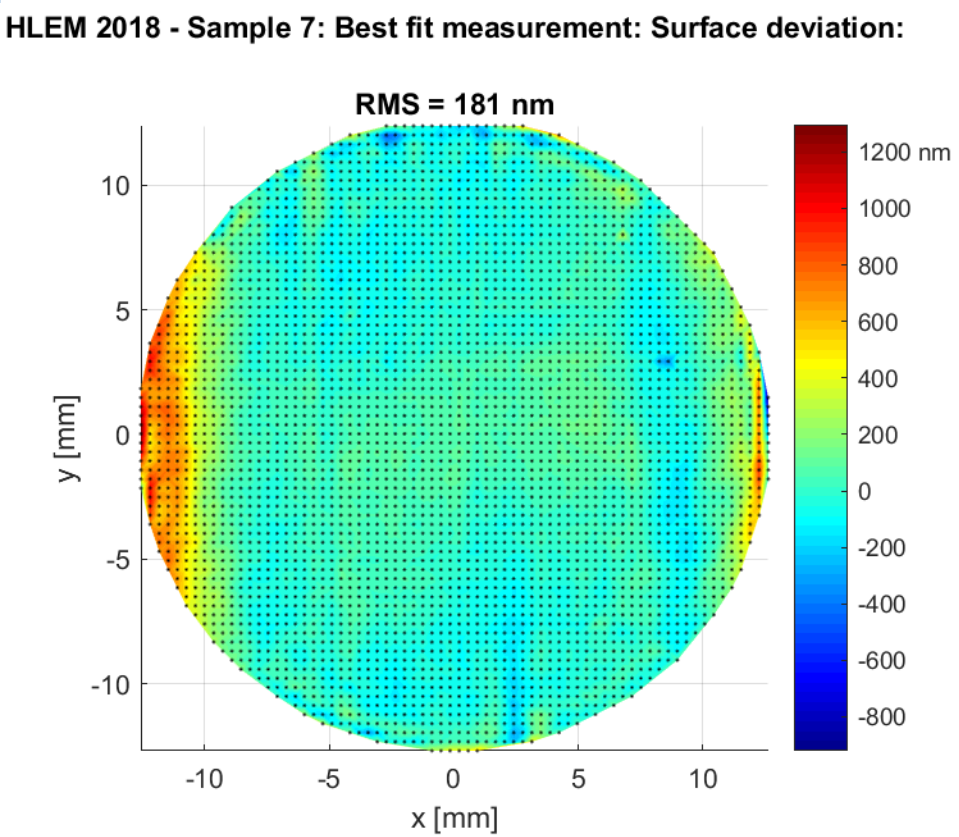
Measurement results: sample 7

- Form deviation w.r.t. theoretical design



– Best fit optimisation performed to determine position and orientation

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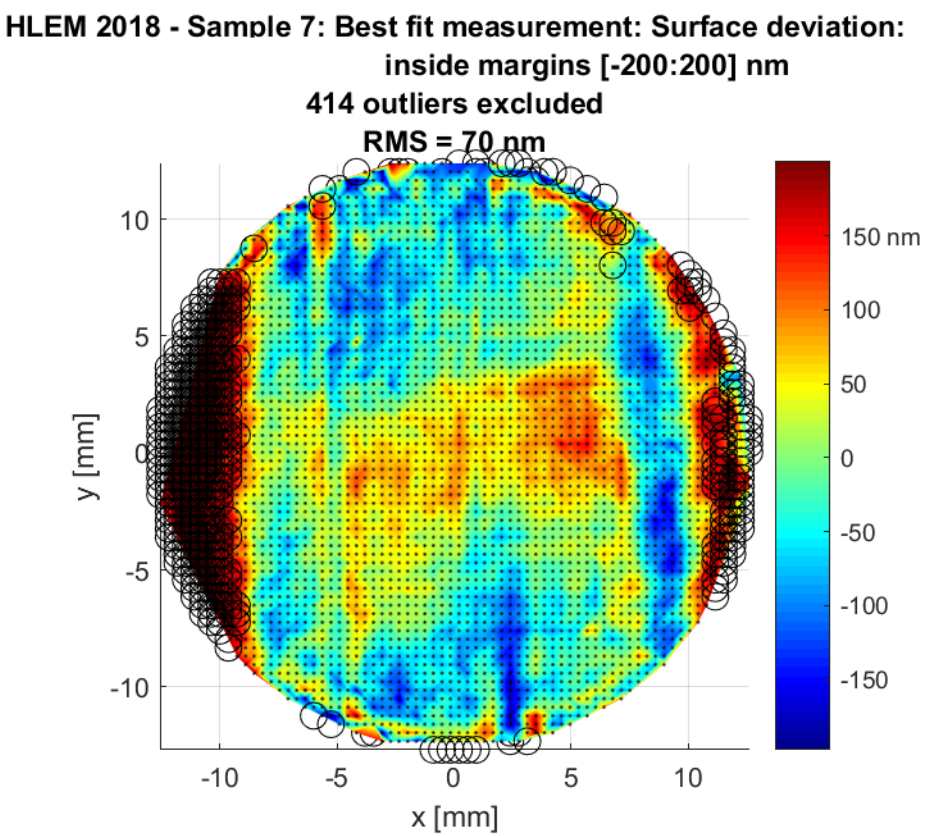
Measurement results: sample 7

- Form deviation w.r.t. theoretical design



- Best fit optimisation performed to determine position and orientation
- Focus on inner part by excluding large deviations

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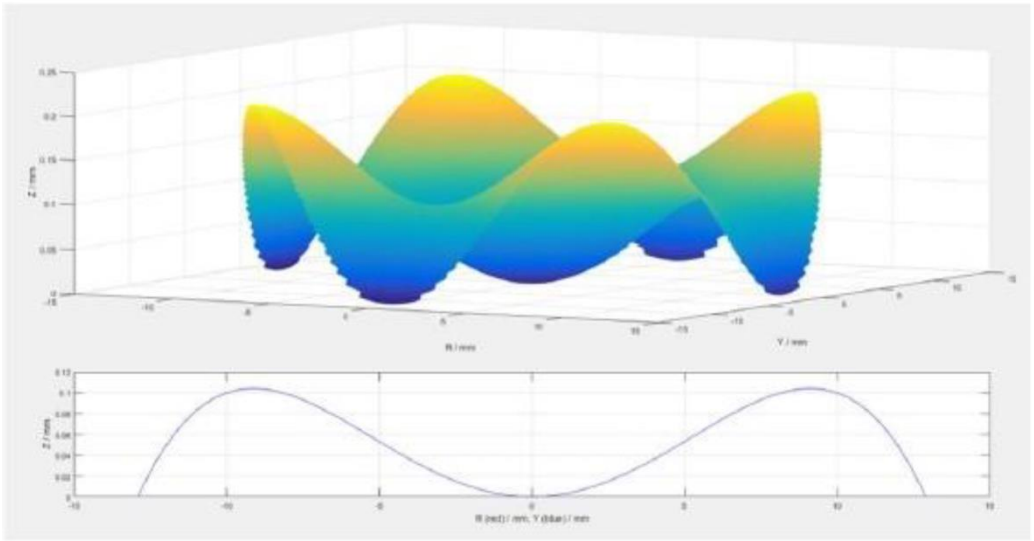
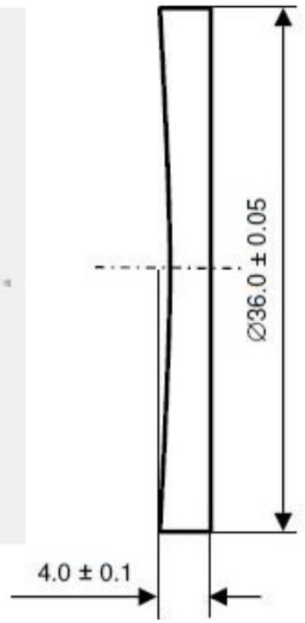
Measurement of sample 8

4th order polynomial freeform
“mild curvature”

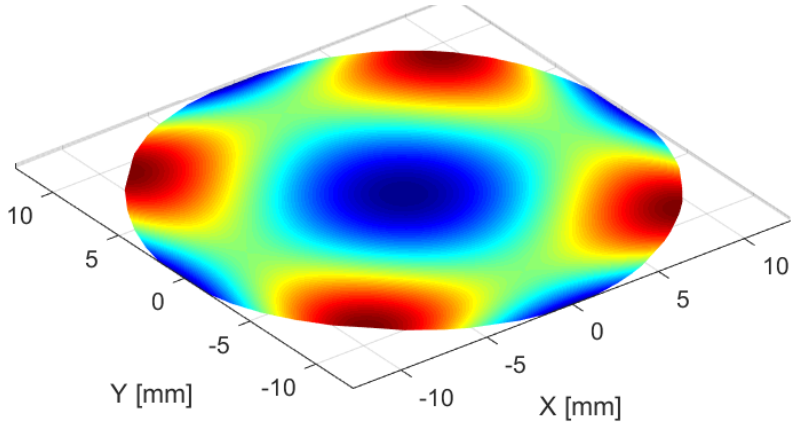
1) $H=Ax^2+By^2+Cx^4+Dy^4$

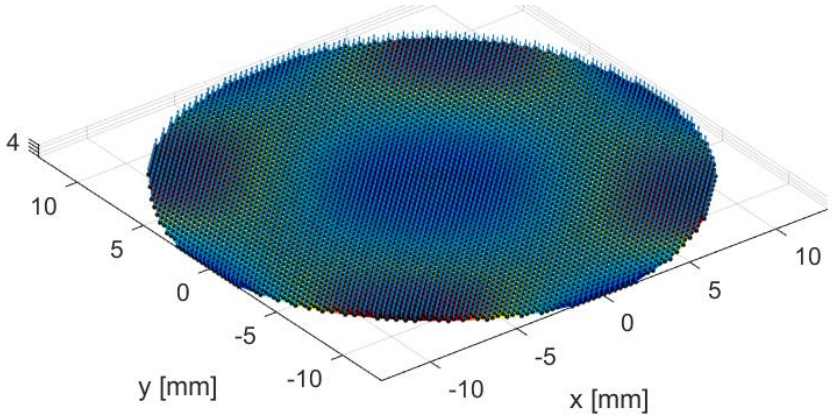




Measurement of sample 8

- Grid spacing: 0.31 mm
- Number of points: 5679
- Measurement time: 15.75 hours
- Measured diameter: 25.7 mm
- Probe used: Triskelion C-500-0012 (Ø 1000 µm Ruby tip)





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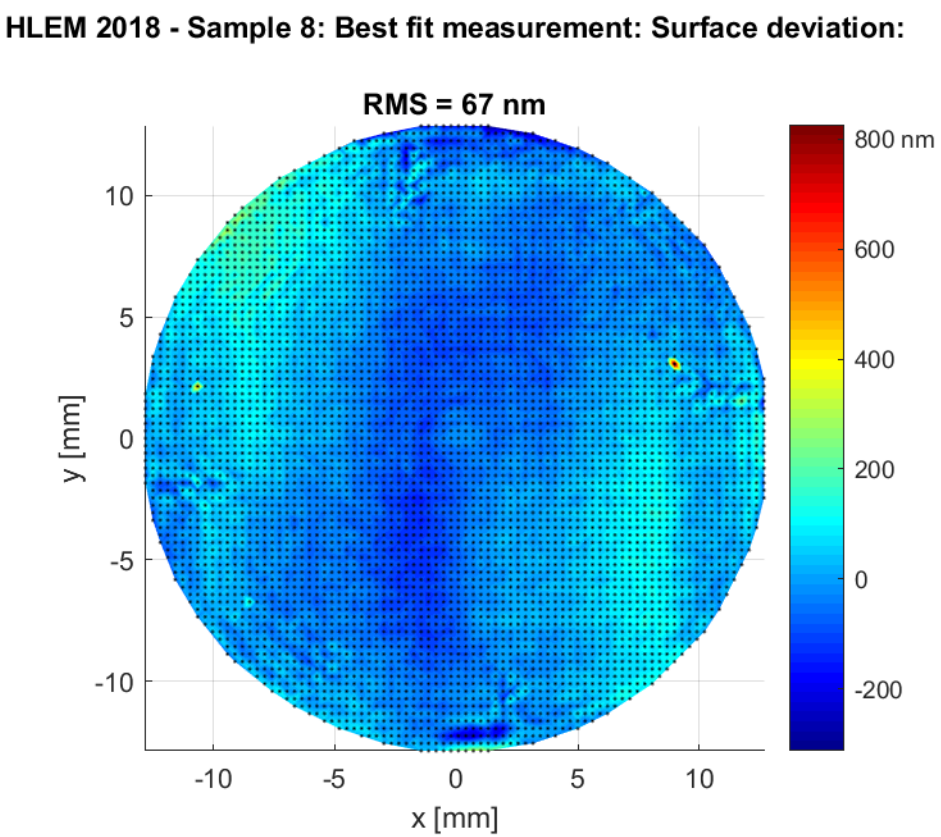
Measurement results: sample 8

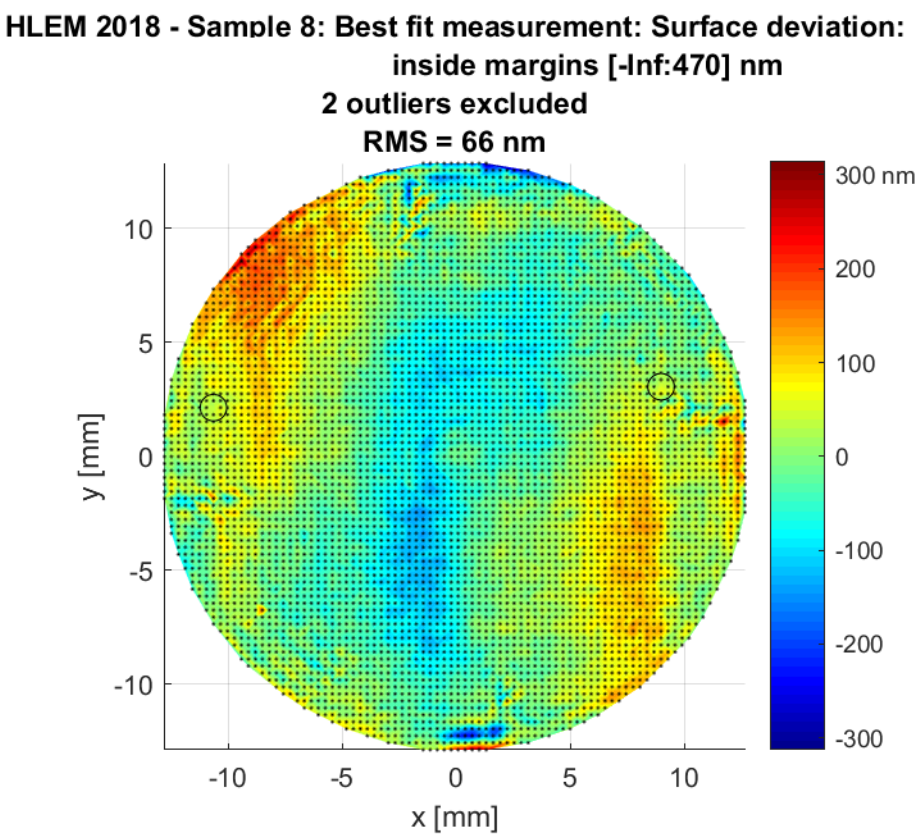
- Form deviation w.r.t. theoretical design



- Best fit optimisation performed to determine position and orientation
- Noticeable contamination

Measurement results: sample 8

- Form deviation w.r.t. theoretical design



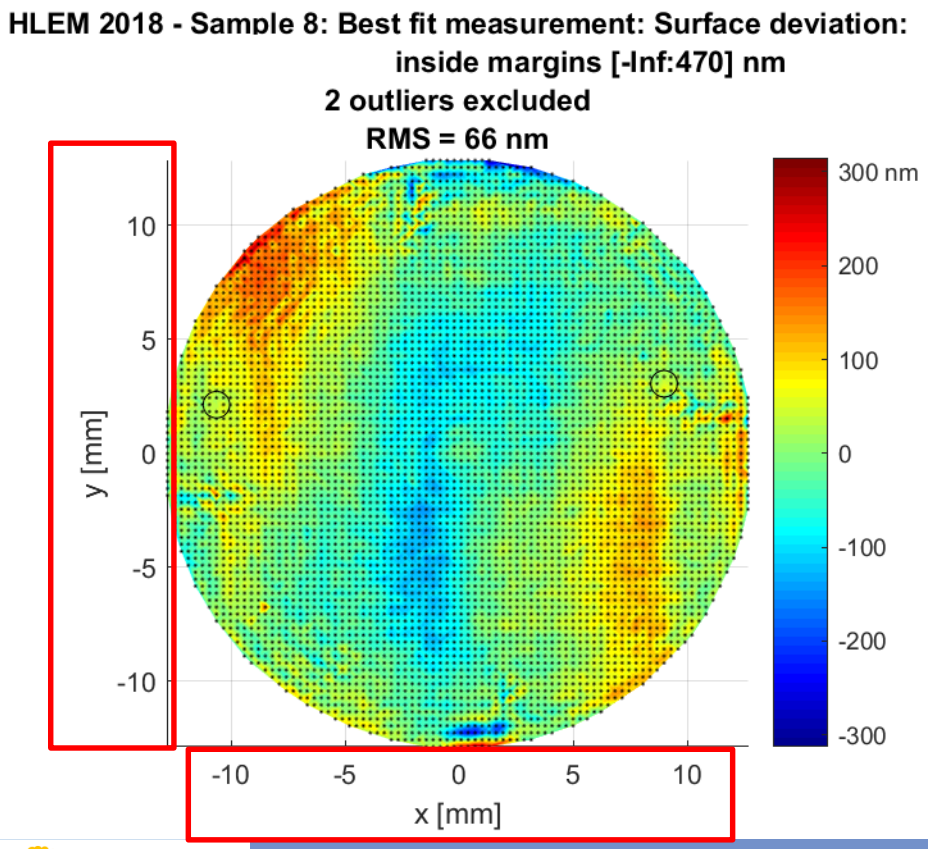
- Best fit optimisation performed to determine position and orientation
- Outliers (due to contamination) excluded. (circles)

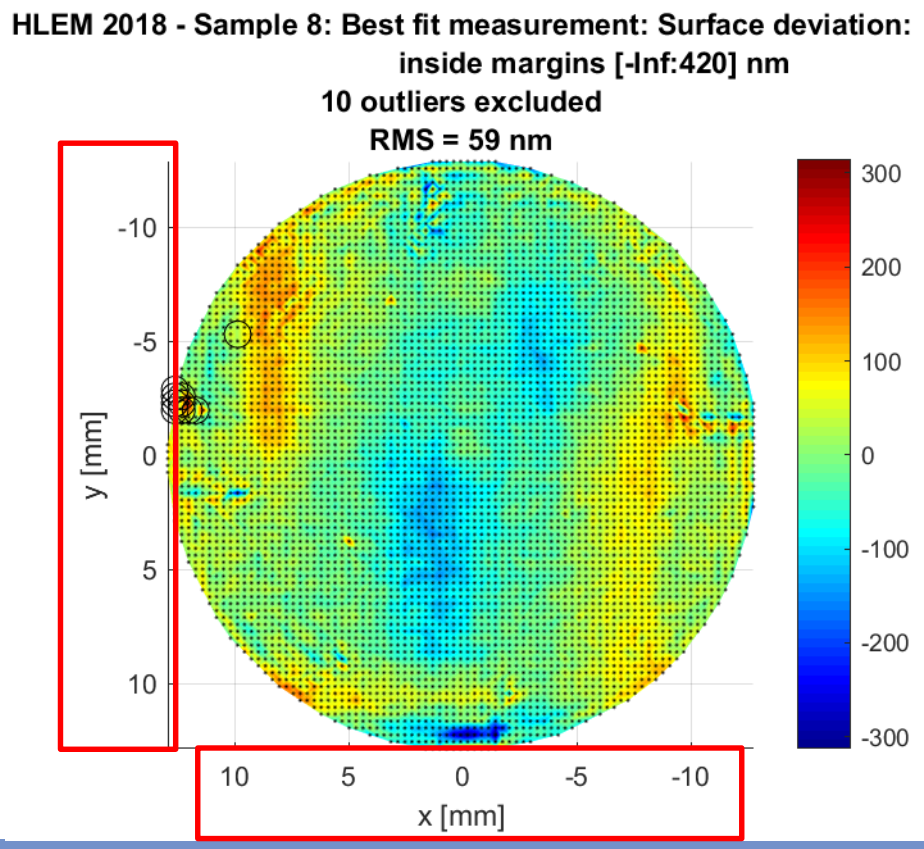
Overview

- Introduction
  - IBS Precision Engineering & Leibniz IOM
  - Isara 400
- HLEM: Aspherical Lens Measurements
  - Setup & Alignment
  - Results
  - Reversal measurement

Measurement results: sample 8

- 180° rotated (Rz) (Contaminated measurements removed)



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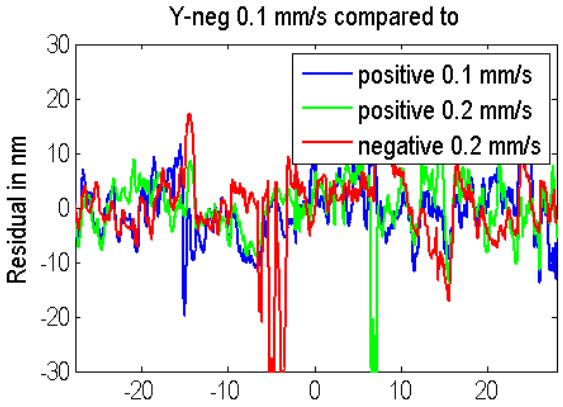
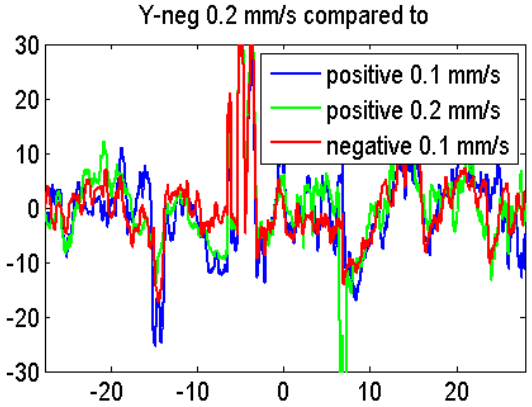
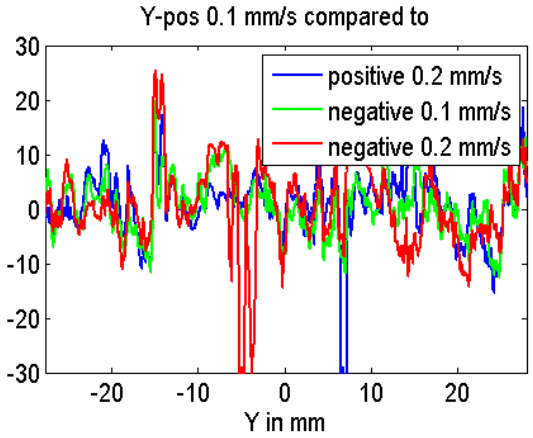
D58 Y-scan repeatability







2σ in nm

	Y- 0.1 mm/s	Y- 0.2 mm/s	Y+ 0.1 mm/s	Y- 0.2 mm/s
Y- 0.1 mm/s	0	13.9853	10.3068	11.1690
Y- 0.2 mm/s	13.9853	0	16.1184	17.6691
Y+ 0.1 mm/s	10.3068	16.1184	0	13.7119
Y- 0.2 mm/s	11.1690	17.6691	13.7119	0

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