A 2D slope measuring system based on Stitching Shack Hartmann optical head

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Collaboration

Imagine Optic

NSLS II

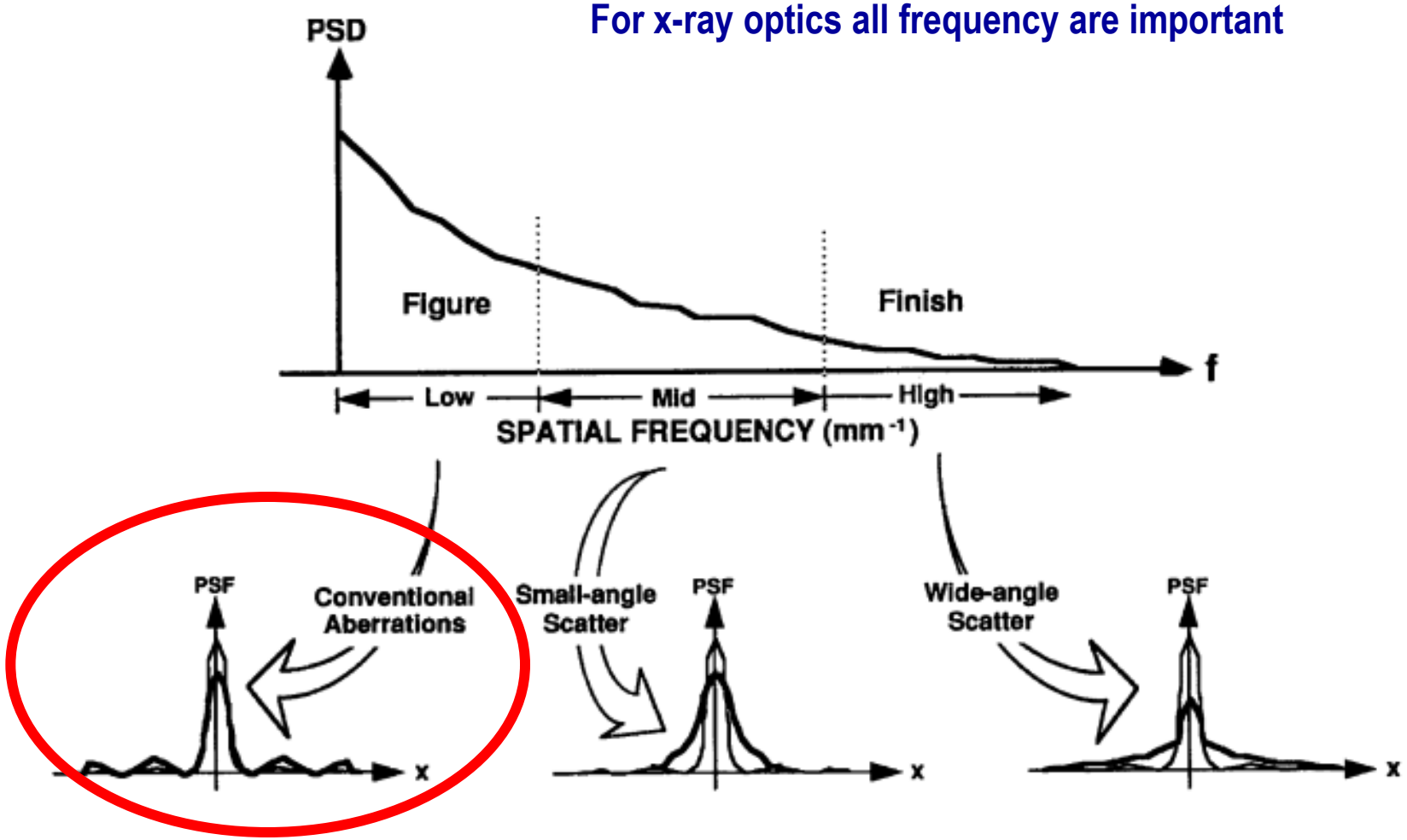
Outline

- Optical Head Description
- *First results*
- *Possible improvements*
- Summary

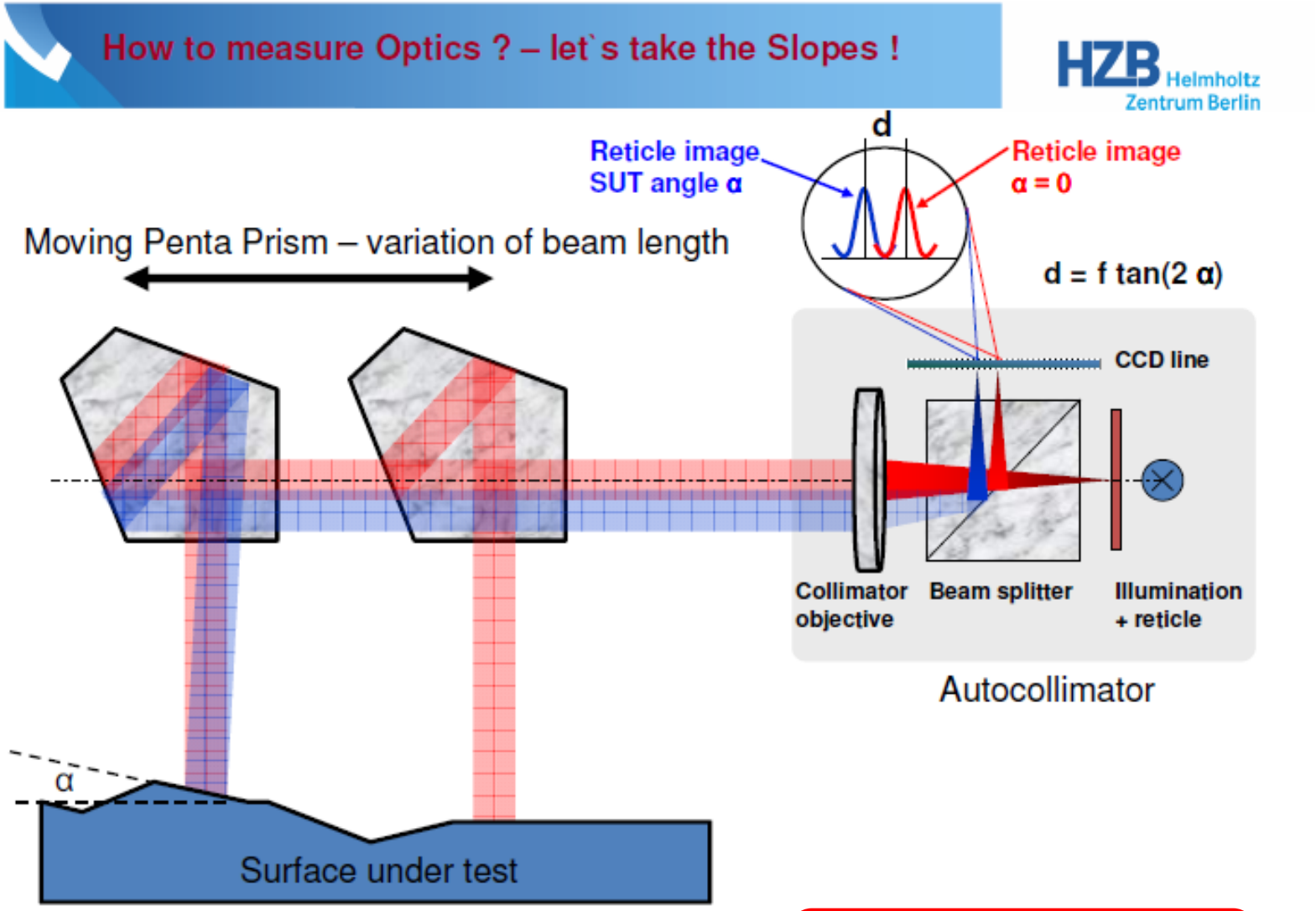
Metrology requirements

Effect of the surface quality differs on each spatial frequency regime

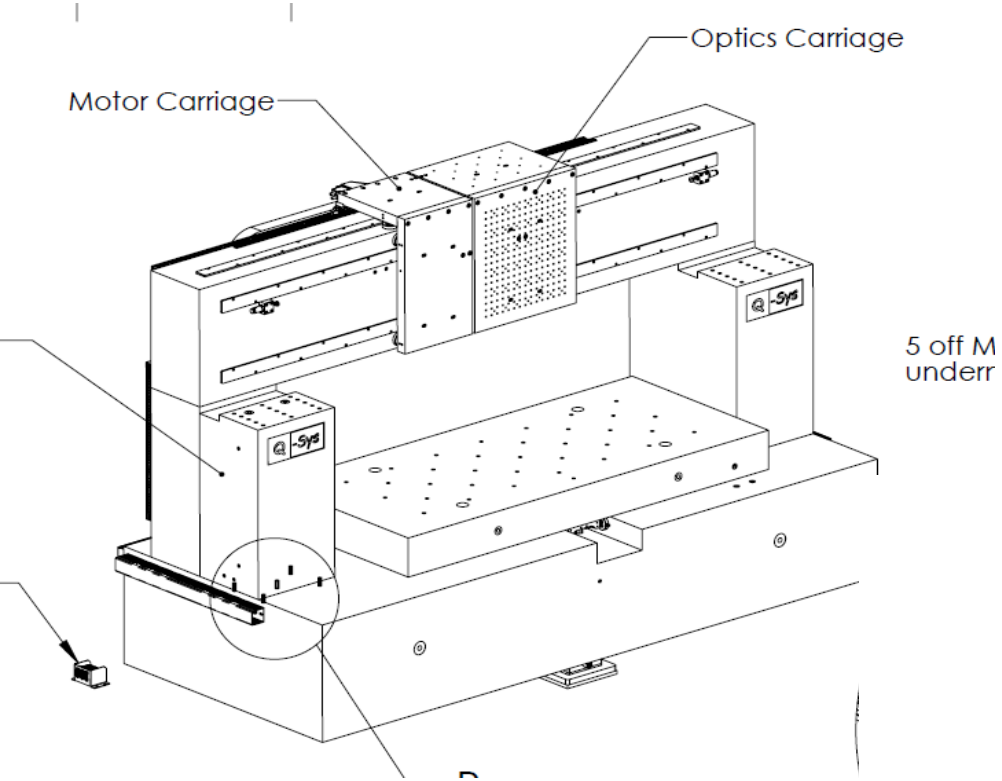
For x-ray optics all frequency are important



Deflectometry based Optical Metrology Station NOM type System



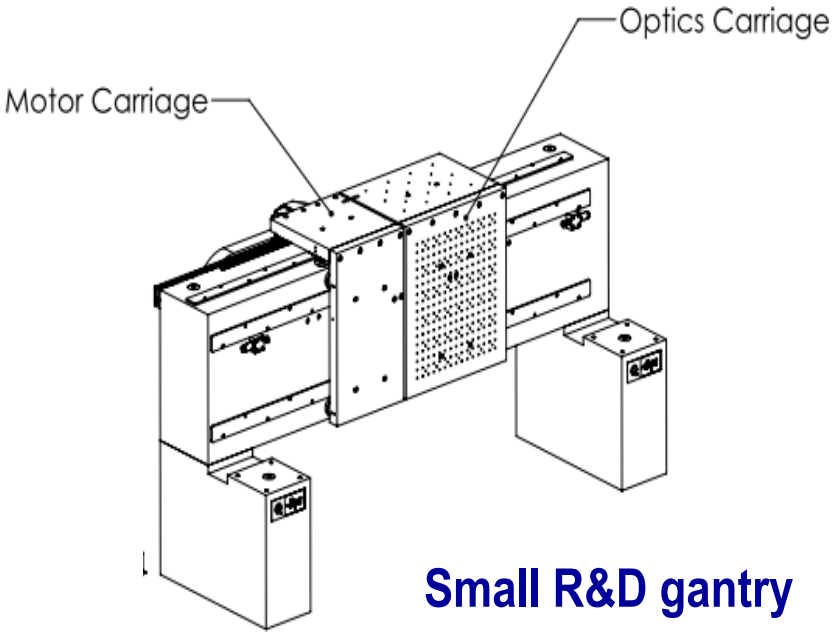
Deflectometry based Optical Metrology Station



Big 2D gantry

2D Travel range : 1500 mm

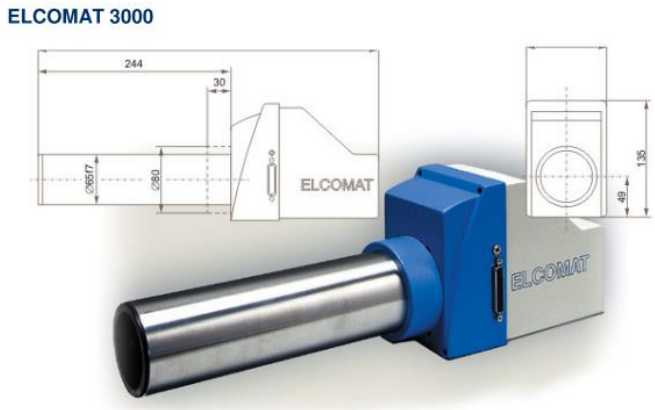
1D Travel range : 990mm



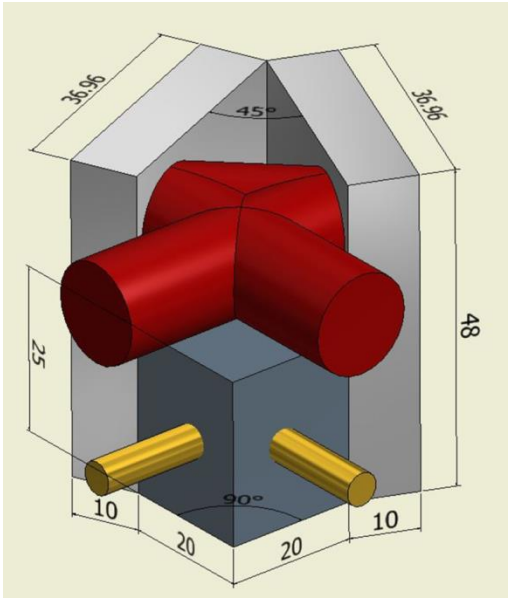
Small R&D gantry

Q -Sys

Shinan Qian

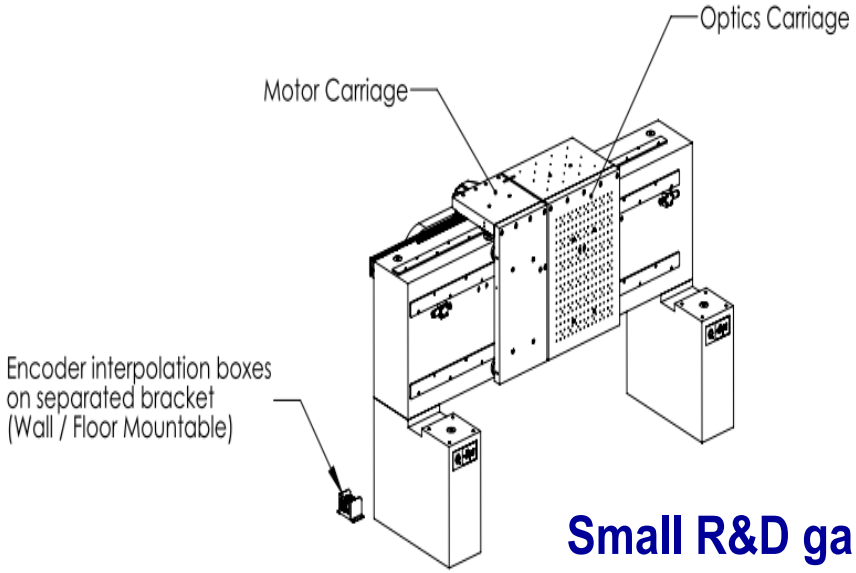


High accuracy Autocollimator



Hollow penta-prism
20 x 20 mm

1D Travel range : 990mm



Small R&D gantry

Q-Sys

Stable and accurate Motion system

Henry Over
Philipp Wallington

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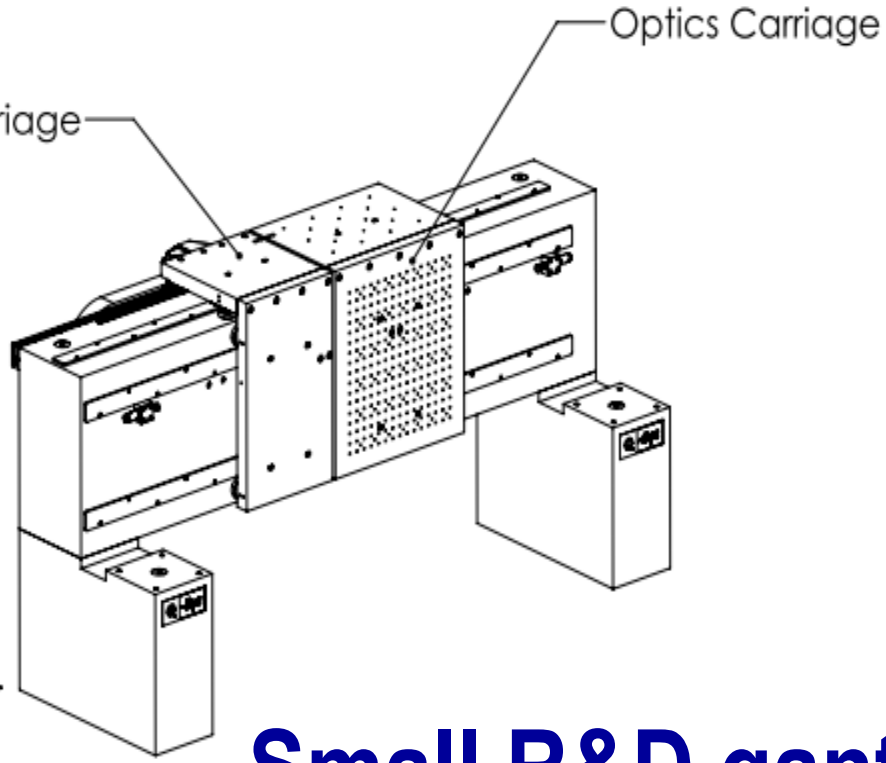
Deflectometry based Optical Metrology Station

Travel range : 990mm



Small R&D gantry

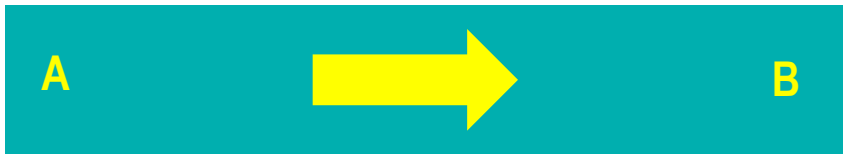
Q-Sys

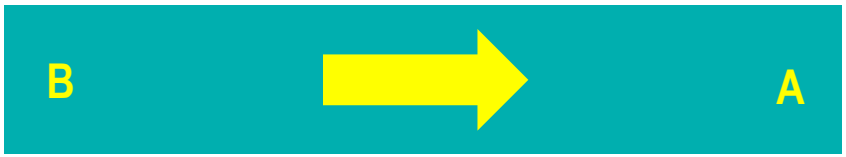
Deflectometry based Optical Metrology Station

Deflectometry based Optical Metrology Station

Flat Silicon mirror

Size: 150 mm x 30 mm x 23 mm
Shape: flat Material: silicon





See Shinan's QIAN poster

NSLS II NOM

Shinan Qian

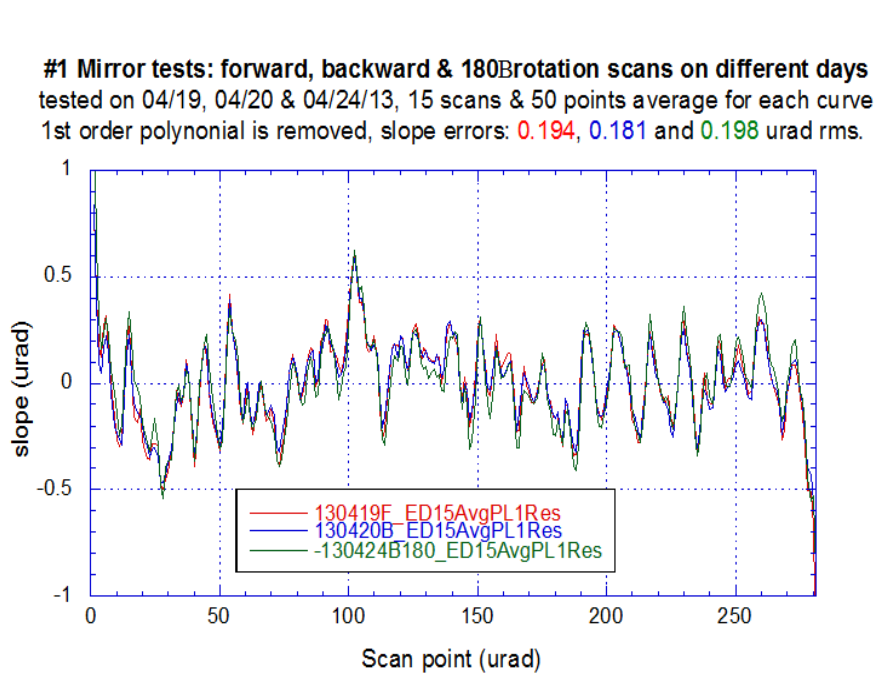


Fig.7 #1 Mirror tests: forward, backward and 180°-rotation scans

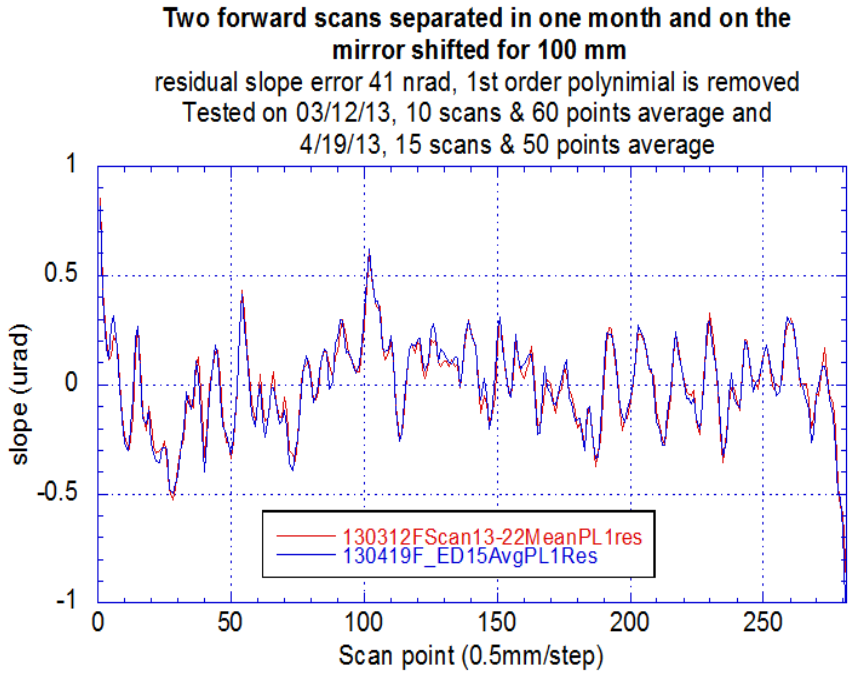
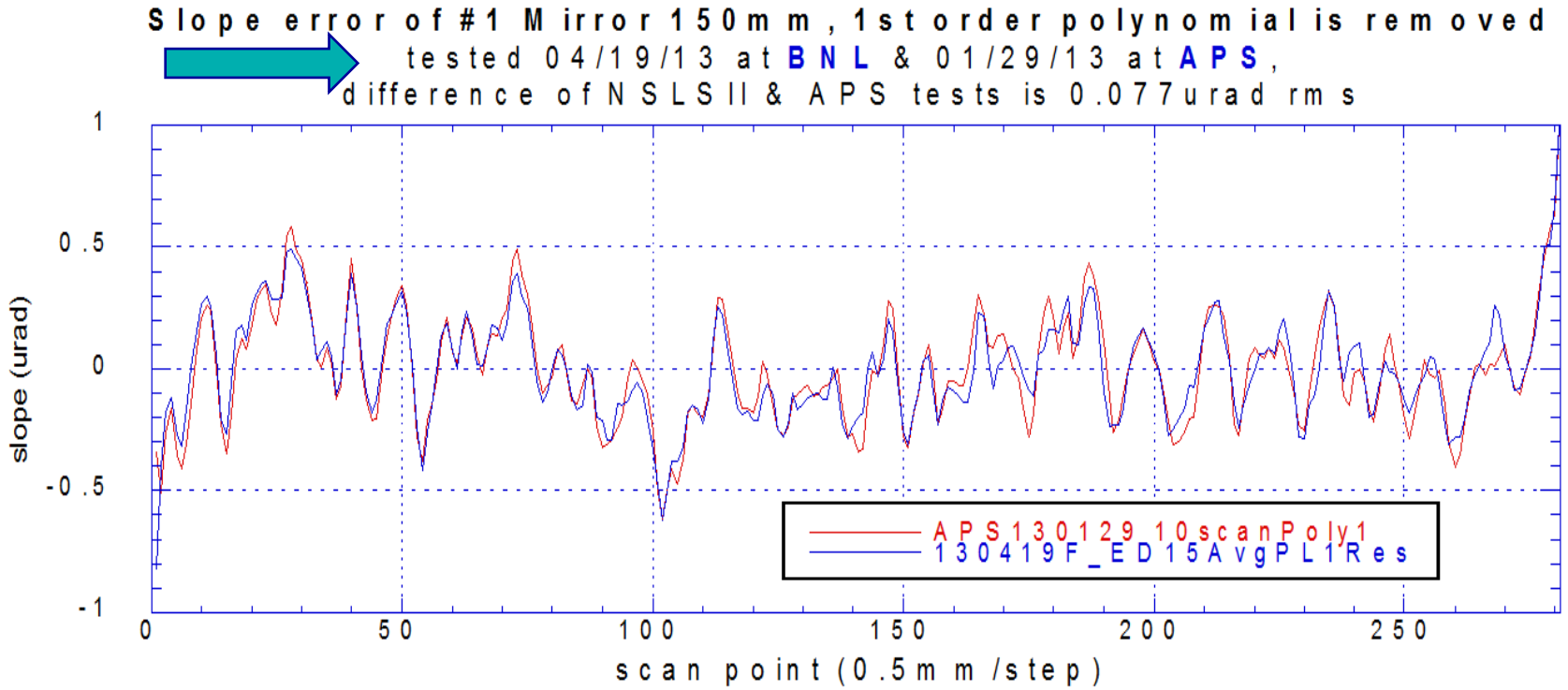


Fig. 8 Two forward scans in one month, mirror shifted 100 mm

Different scans	15 scans	F-B	F-R	B-R	F-FM & shift 100mm
Repeatability (nrad rms)	75	35	61	63	41

NSLS II NOM – APS NOM

Shinan Qian
Lahsen Assoufid – J Qian (APS)



Comparisons of #1 mirror 150mm with NSLSII-NOM1 and APS-NOM tested on 4/19/13 and 1/29/13, error 77nrad rms

Height error difference is 0.3 nm rms

A 2D slope measuring system based on Shack Hartmann optical head

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Deflectometry based Optical Metrology Station

NOM type machine : Design

Parameter	Specification
Platform dimensions [mm]	2600(w)x 1100(d)x1700(h)
Platform weight [kg]	5500
Electrical supply voltage and load	230Vac 5A rms
Electrical supply type	50/60 Hz single phase
Air supply pressure	6 – 7 bar
Air consumption	30 l/min
Air dew point	-20 degC at 1 bar

Travel has been maximized at 1500 mm

Optical Head
~ 25 kg

Optical Platform
~ 200 kg

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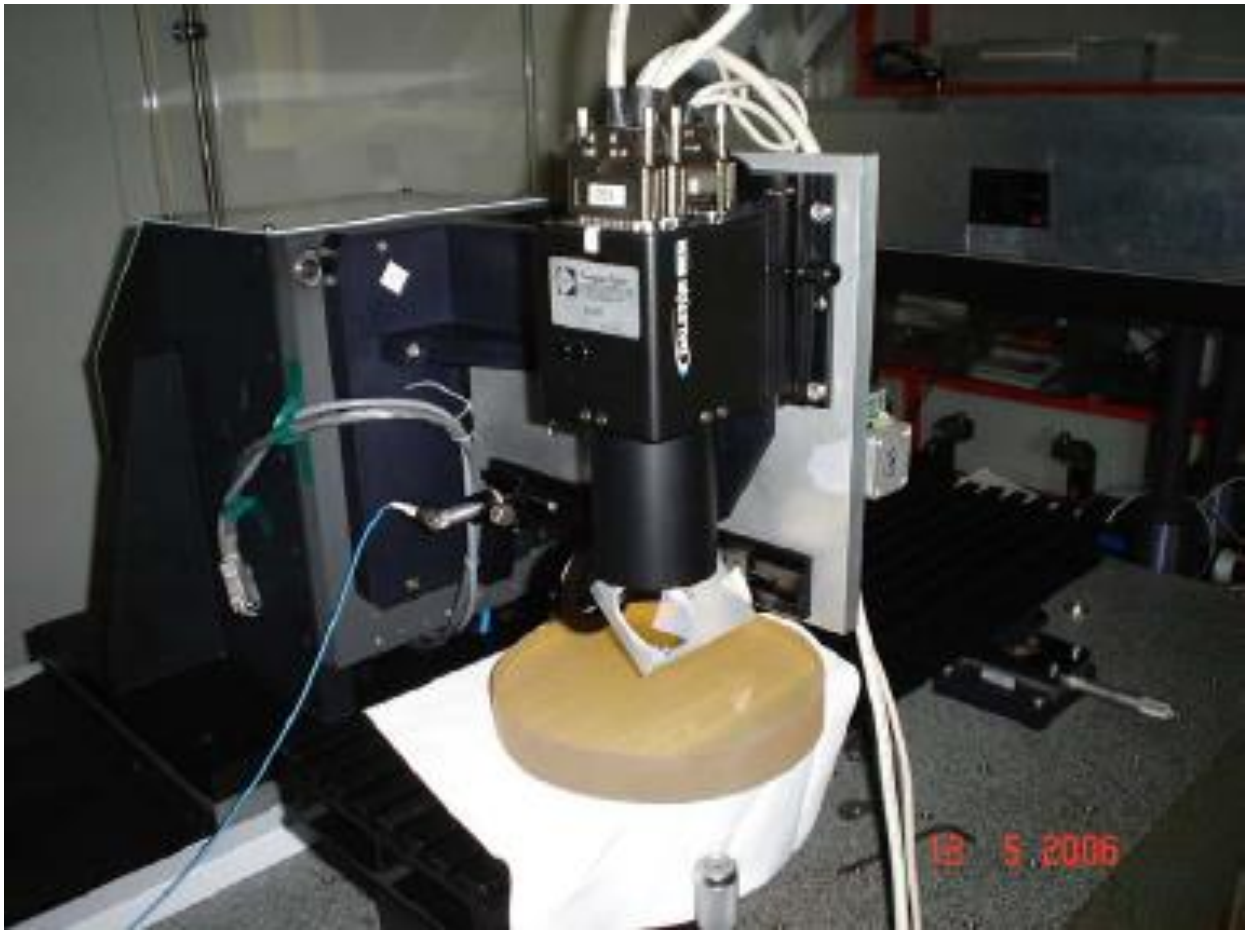
Deflectometry based Optical Metrology Station

Stitching Shack Hartmann head for Long Trace Profiler : SSH-LTP



Imagine Optic

SOLEIL SYNCHROTRON

From Muriel Thomasset / SOLEIL

Imagine Optic/France

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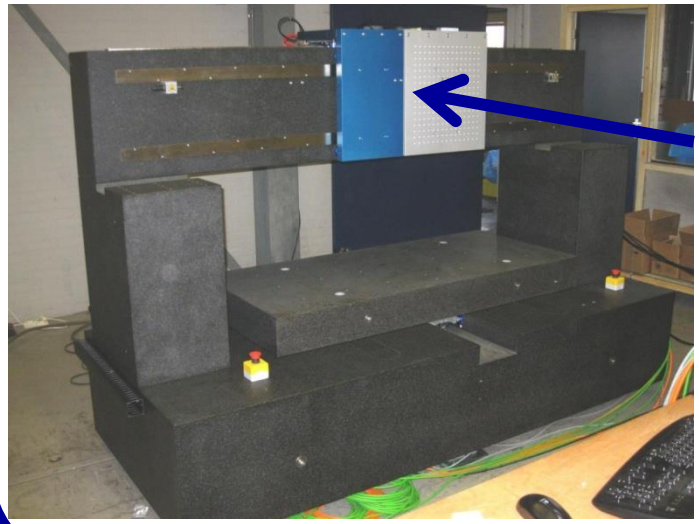
Stitching Shack-Hartmann Wavefront system Concept

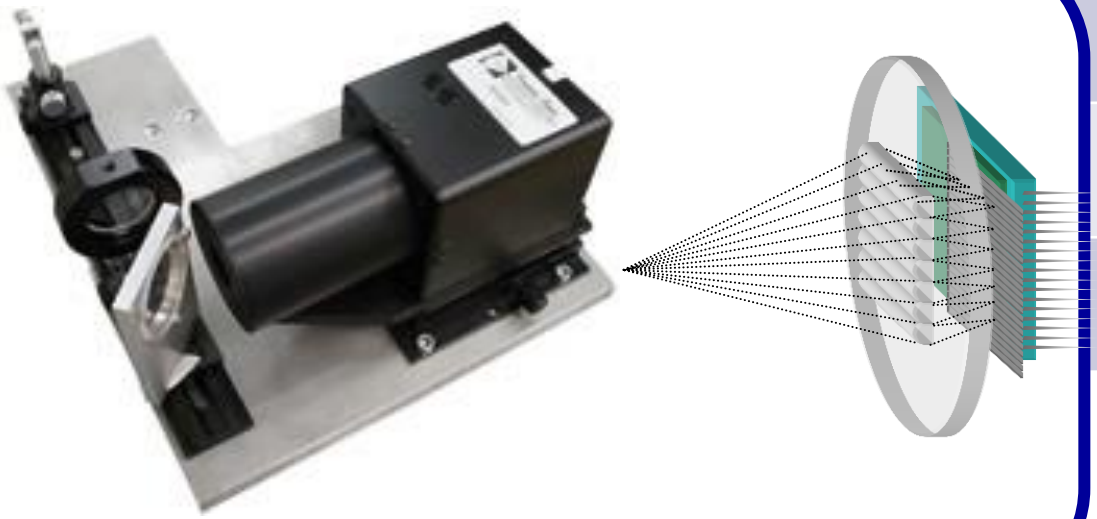
Problem : Measured 1.5 meter long mirror with 50nrad rms accuracy, highest possible spatial resolution with mirror radius as low as possible.

Solution :

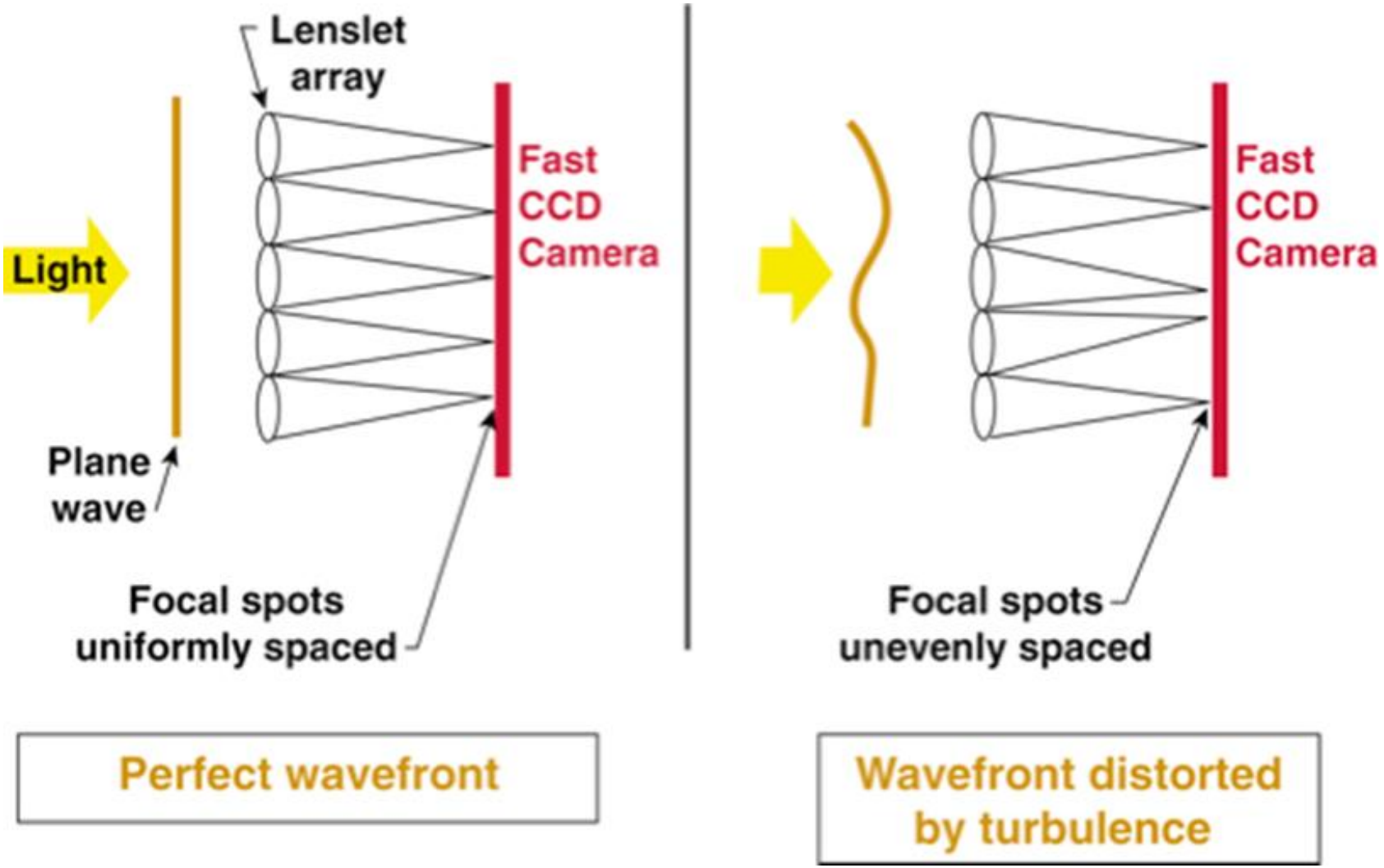
1. **very sensitive wavefront sensor +**
2. **source +**
3. **translation stage +**
4. **stitching algorithm**

Shack-Hartmann Wavefront sensor	
Number of points	15 x 11
Pupil size	18 x 13 mm



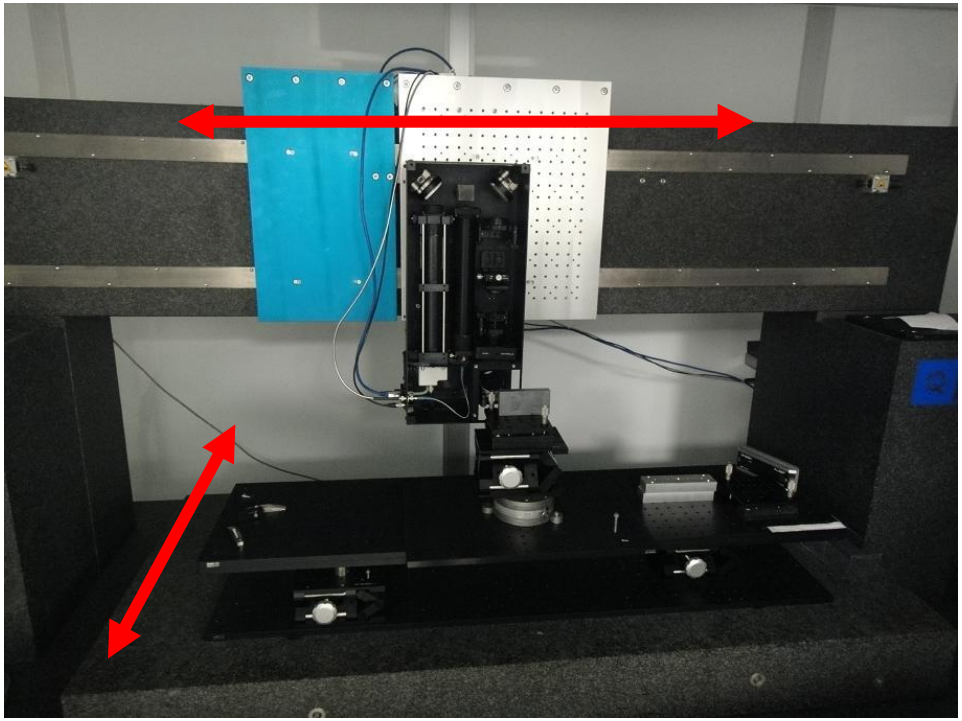


Shack-Hartmann Wavefront sensor Concept



Stitching Shack Hartmann Optical Head : SSHOH

System installed at BNL



System as designed

Collaboration between Imagine Optic **(France) and NSLS II**

Gantry from Q-Sys

Office of Science
U.S. DEPARTMENT OF ENERGY

Henry Over
Philipp Wallington

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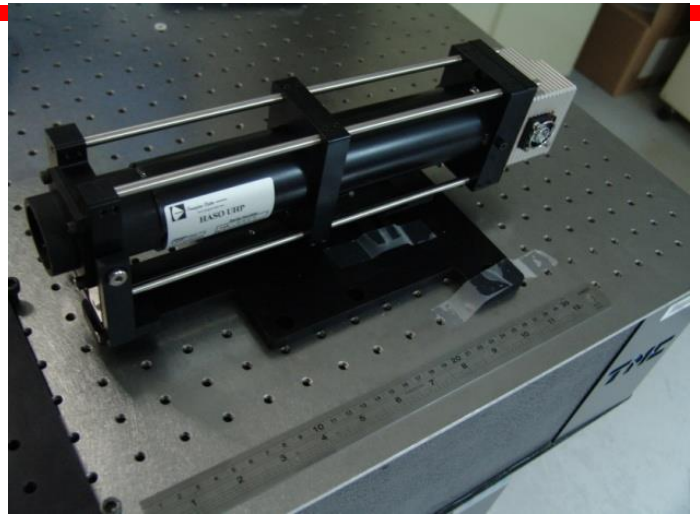
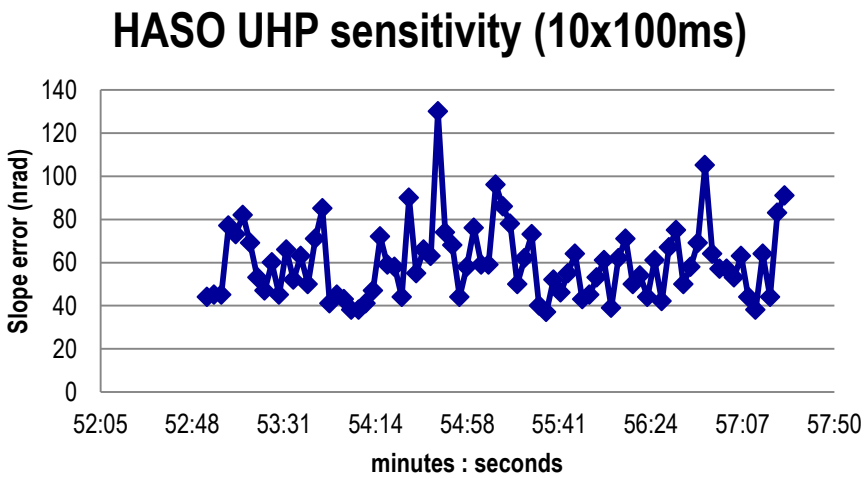
The wavefront sensor

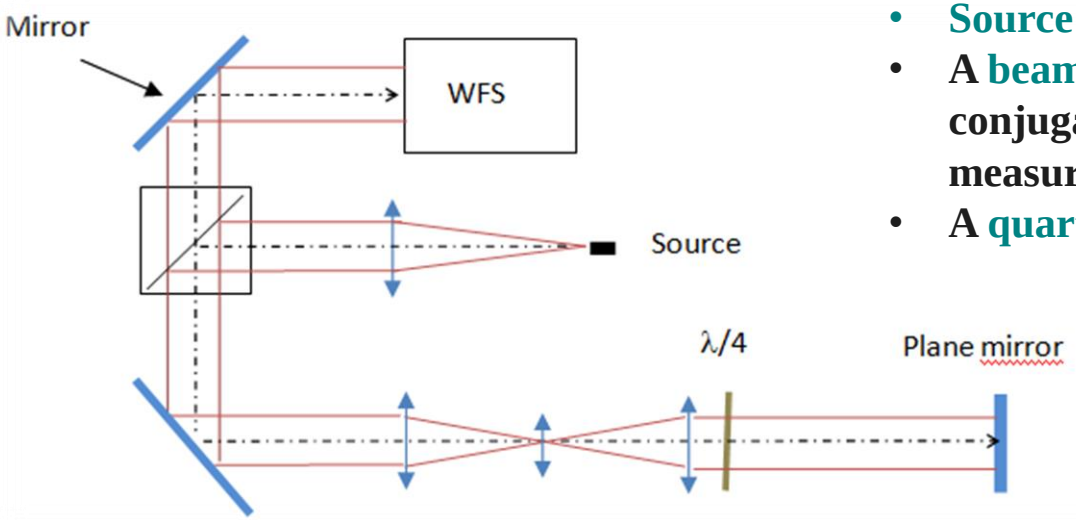
Shack-Hartmann Wavefront sensor	
Number of points	15 x 11
Microlenses size	1.2 x 1.2 mm²
Sensitivity	Down to 40 nrad rms



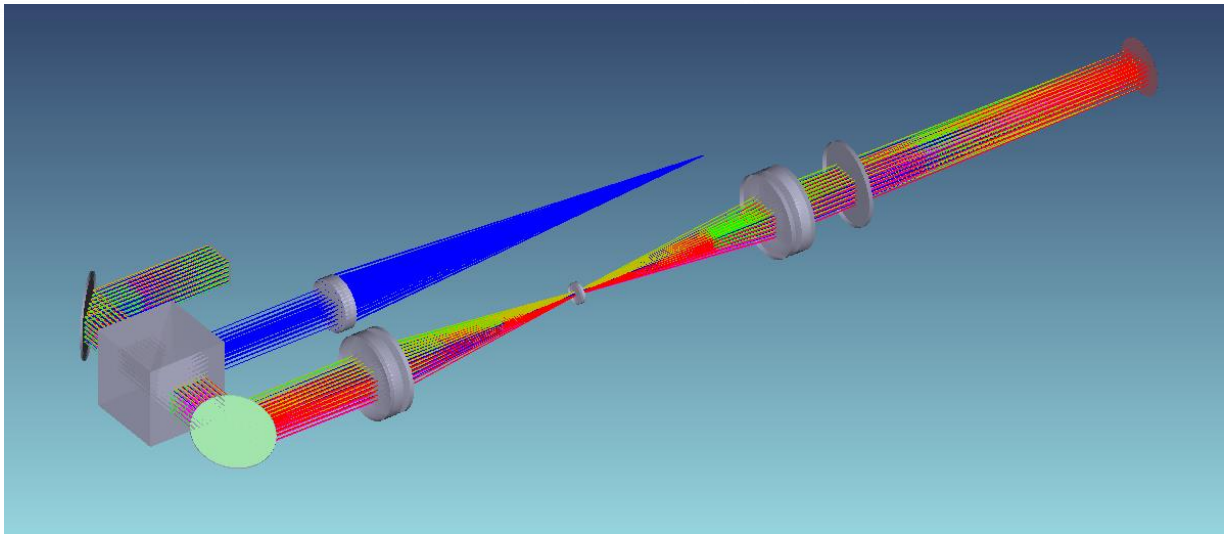


The impact of air turbulences is very important.
Averaging 10 images allows to reach 40nrad rms…

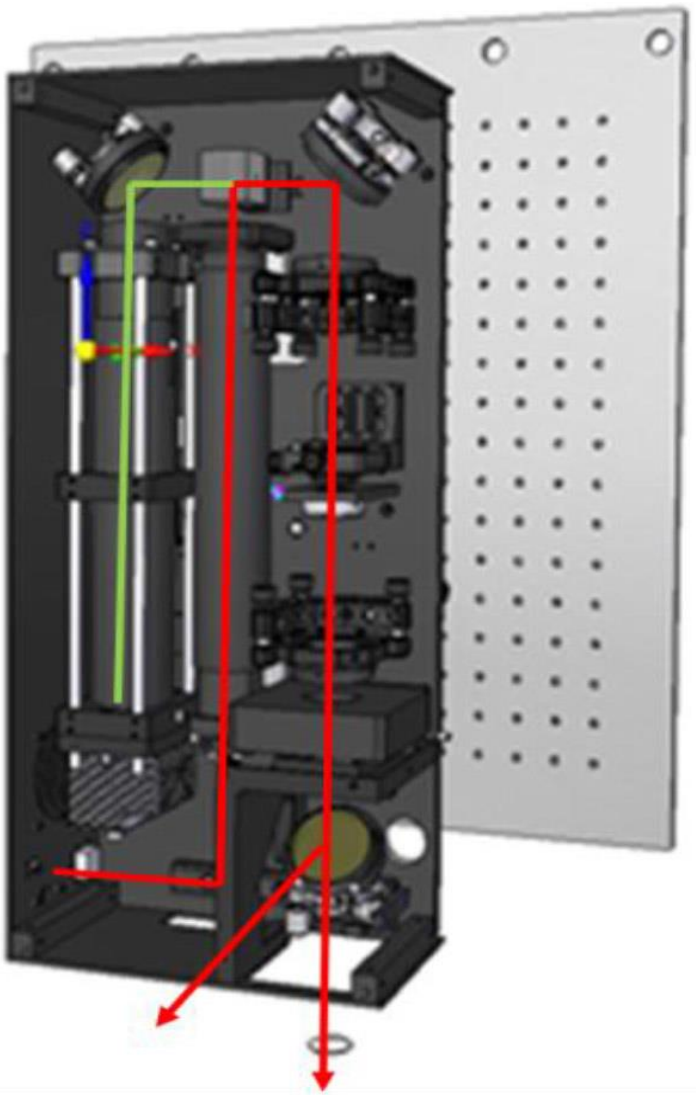
The source and pupil imaging

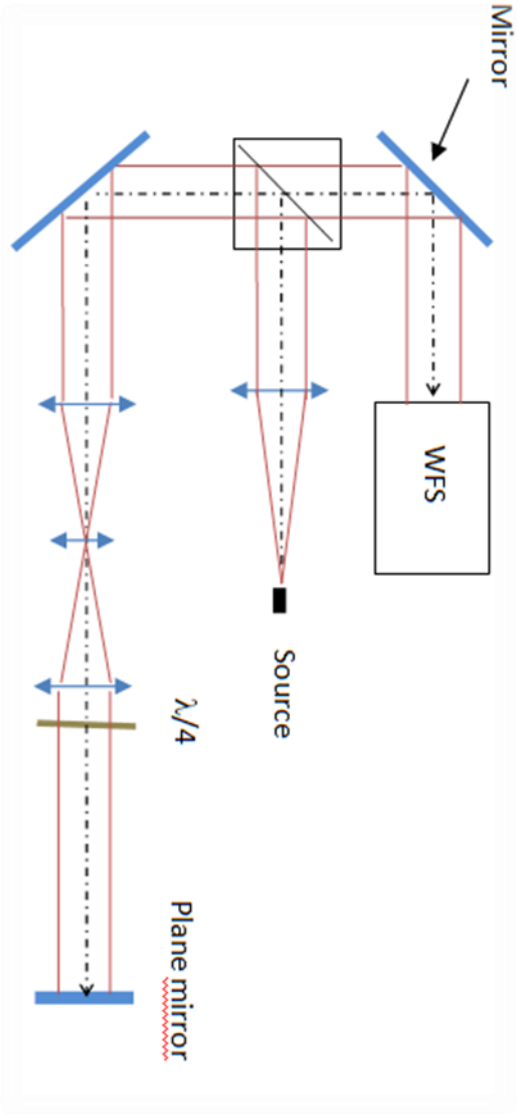


- **Source is a fibered laser diode at 405 nm.**
- **A beam expander (magnification = -1) allows a conjugation between the mirror under measurement and the microlenses array**
- **A quarter wave is needed to remove all ghosts**

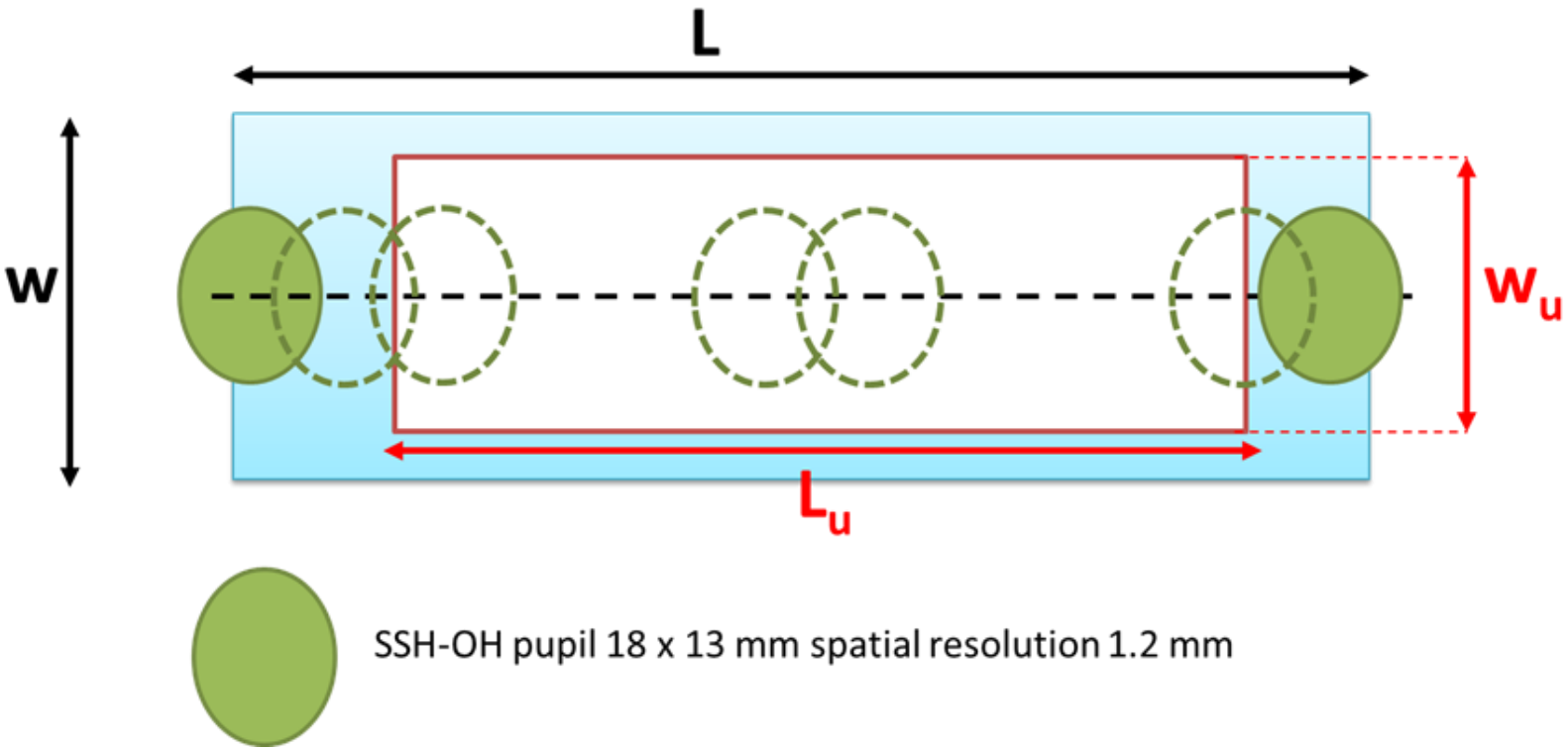


The mechanical design





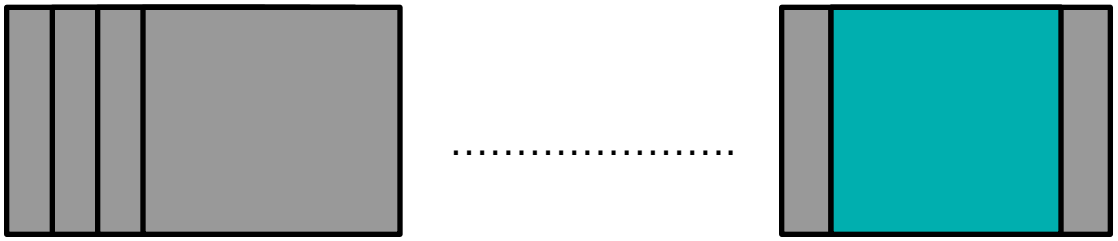
Measurement principle



Stitching principle and SSH-OH parameters

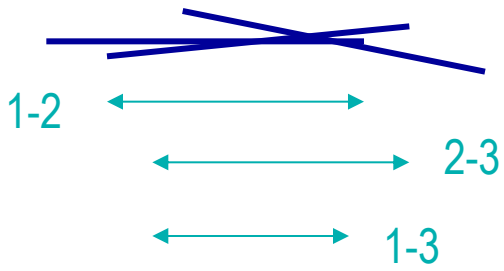
The Stiching algorithm

Needed to remove the translation stages errors and build the entire surface map



On the overlap area : the measured slopes must be the same

Translation stages errors can be calculated by measuring the tilts in all the common areas

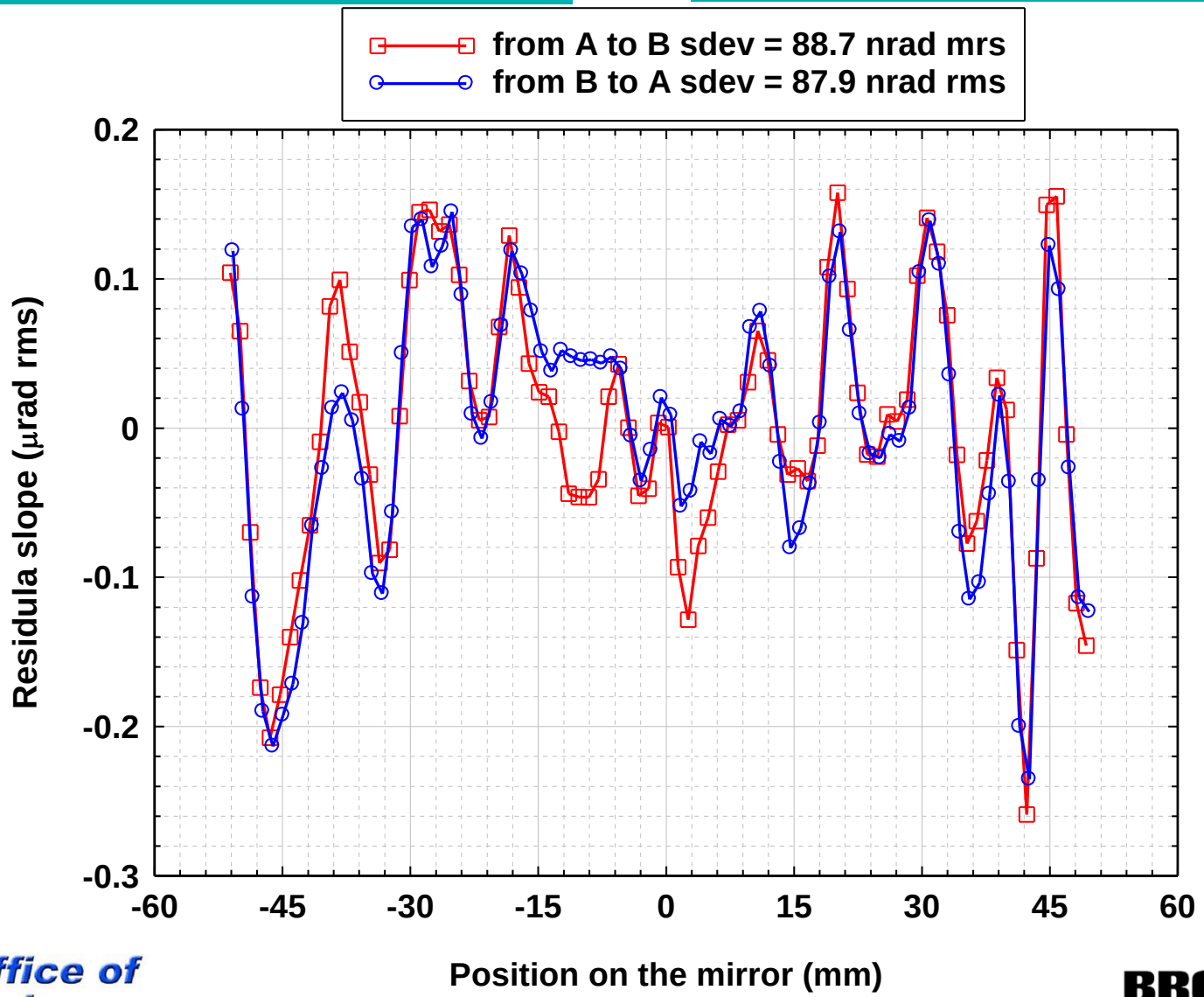


As there are many overlap areas, the algorithme uses all these data to calculate the best possible stages errors (LSM approach) that explains all the measured differences in these common areas

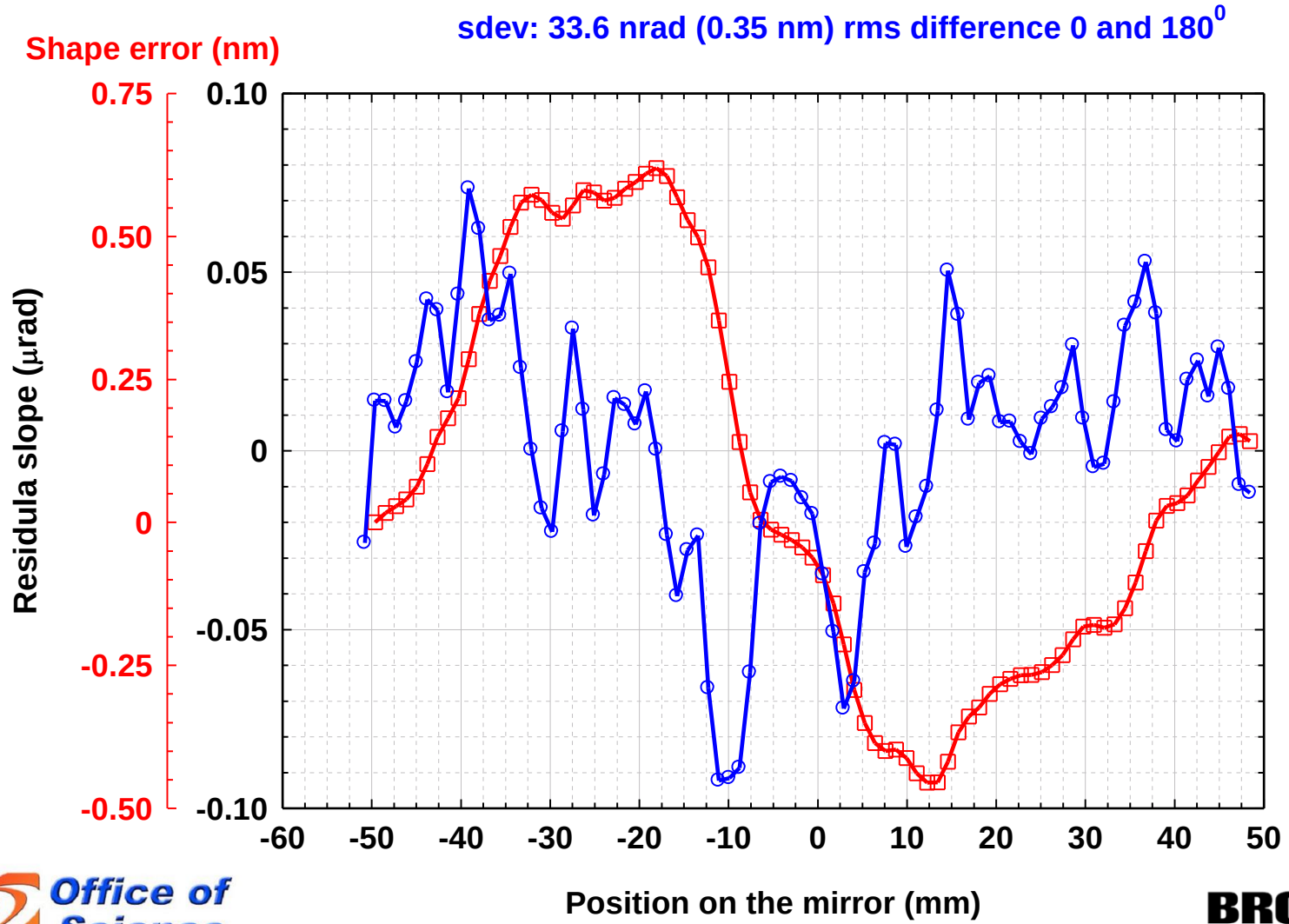
Translation errors are then subtracted to the raw data and data are finally averaged

Some results

Flat Silicon mirror

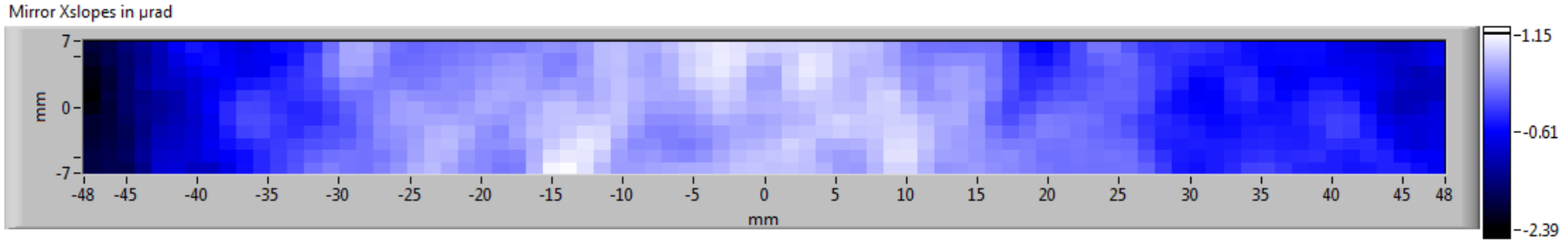


Flat Silicon mirror



Results on a flat mirror

Average of 26 scans on a flat mirror (100mm long)



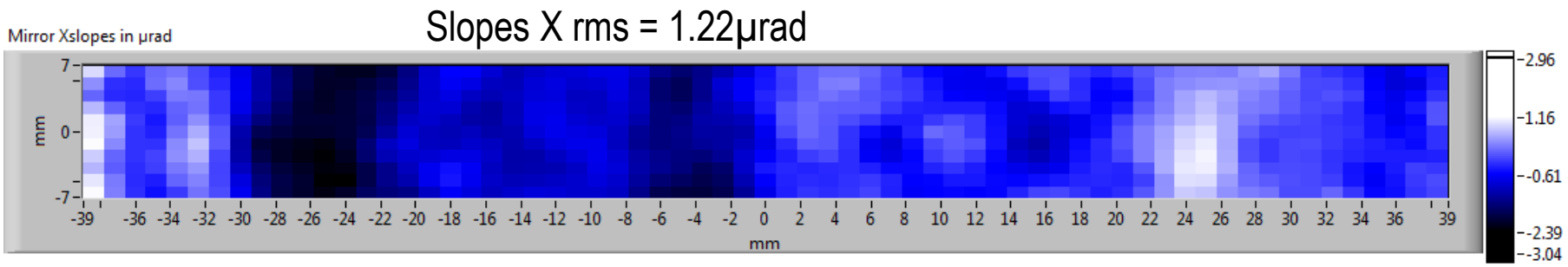
Slopes X rms = 0.69µrad

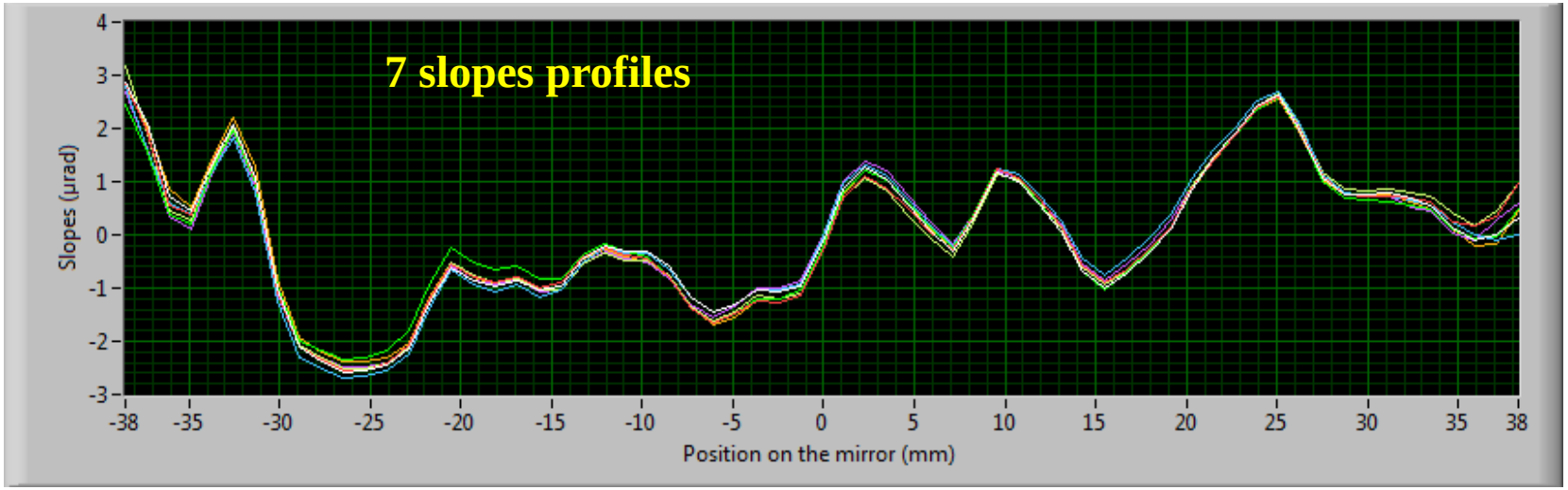
26 slopes profiles

30 nrad rms of repeatability obtained after subtracting best sphere

Results on a spherical mirror (RR02)

Average of 7 scans on a spherical mirror (80mm long, radius 55m)



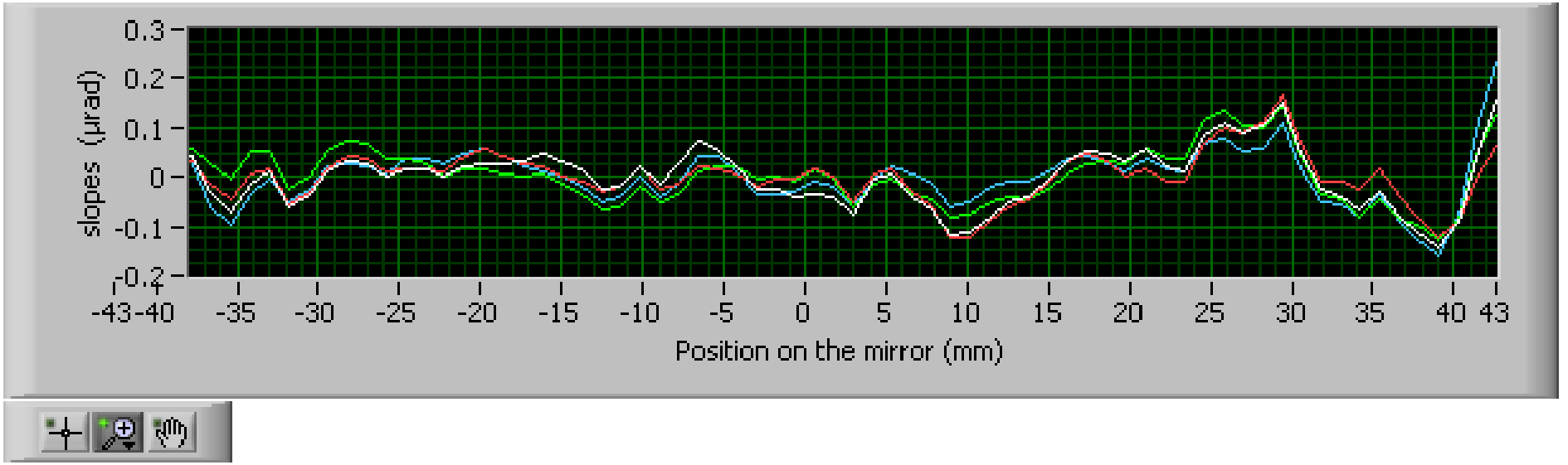


90 nrad rms of repeatability obtained after subtracting best sphere

Preliminary results on a 1D elliptical mirror

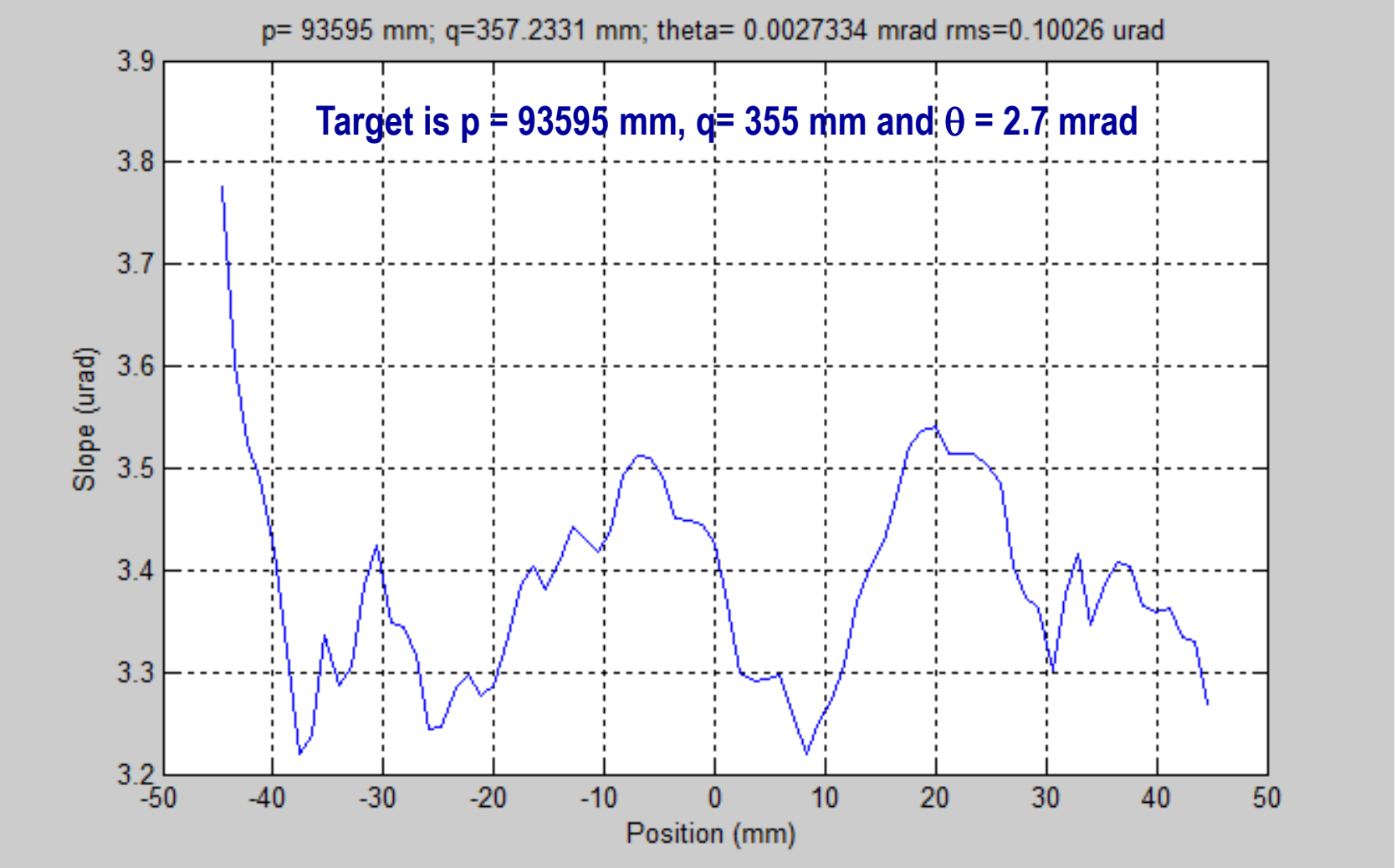
Systematic errors estimation :

same ellipse measured with angles from 0 to 1 mrad

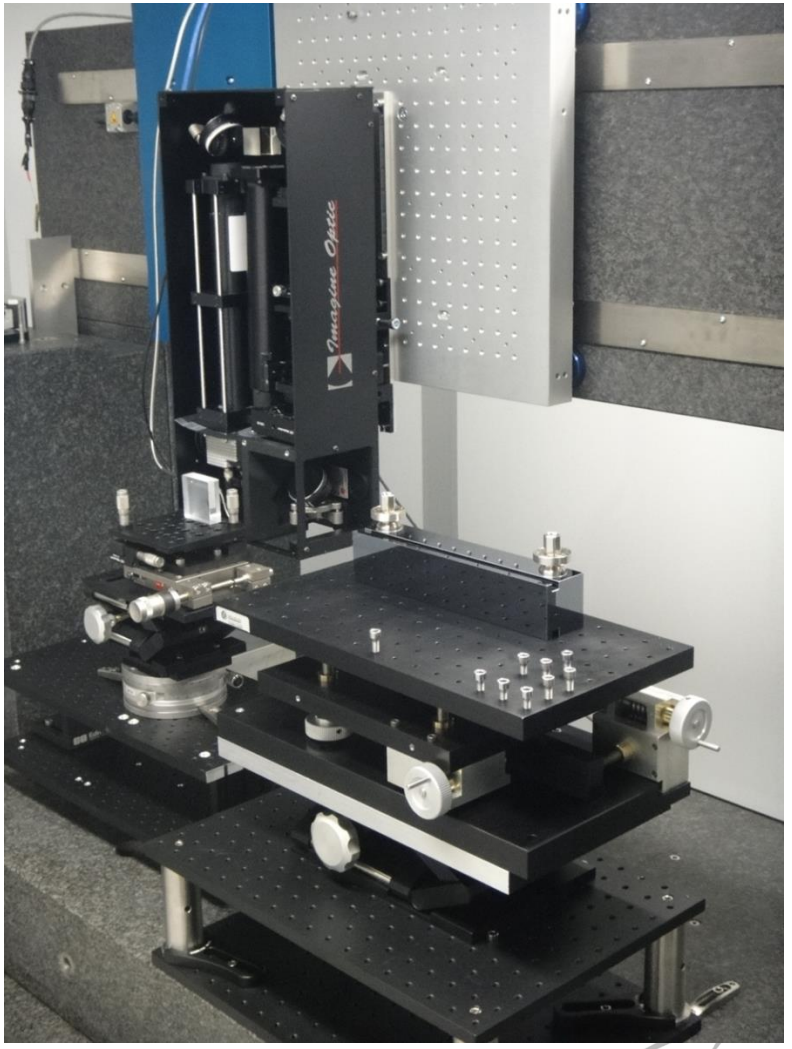


Delta slopes = 20 nrad rms

Preliminary results on a 1D elliptical mirror

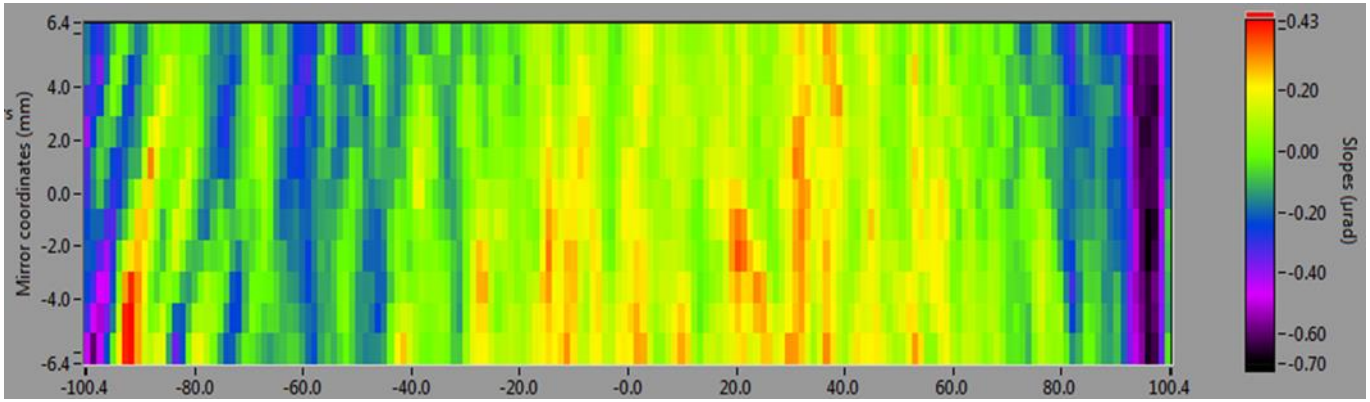


M2A CSX



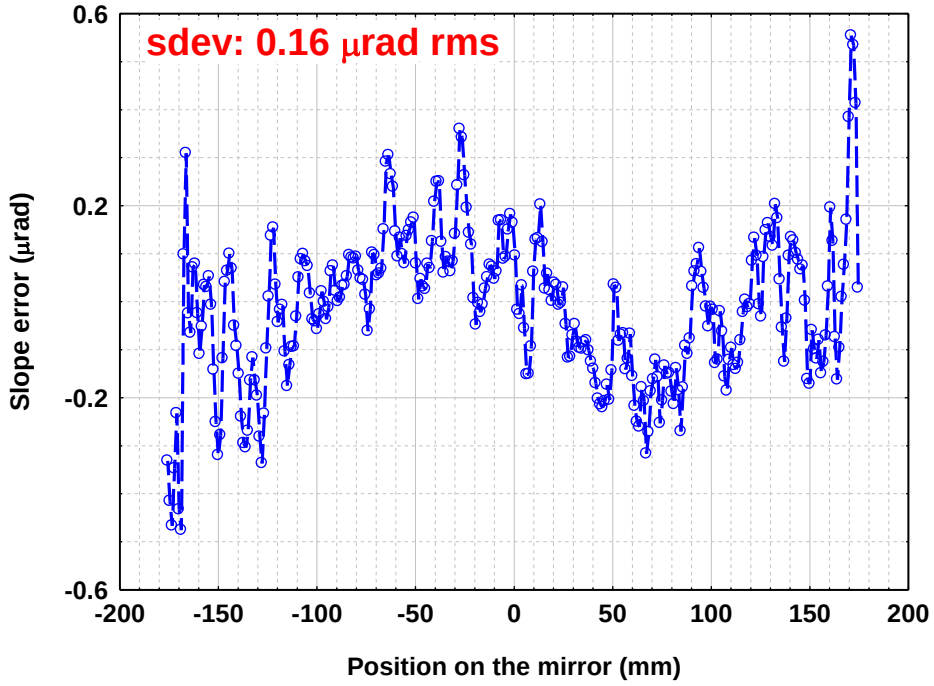
M2A CSX

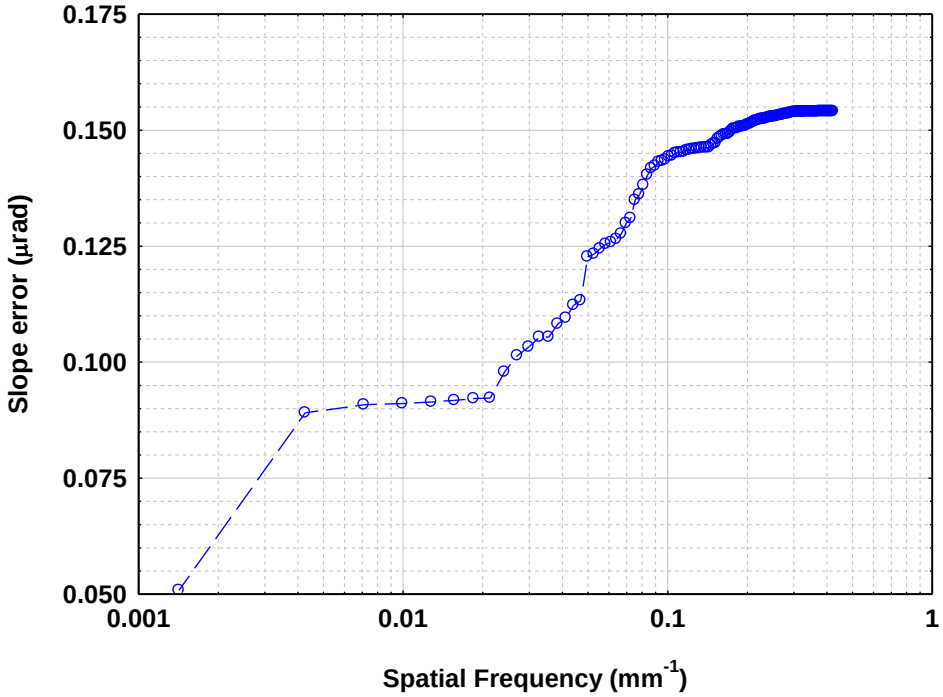
		Best radius removed	
Rx (km)	Ry (km)	X slope urad rms	Y slopes urad rms
-267.16	21.341	0.16	0.2



2D Map of Residual slope error of the mirror

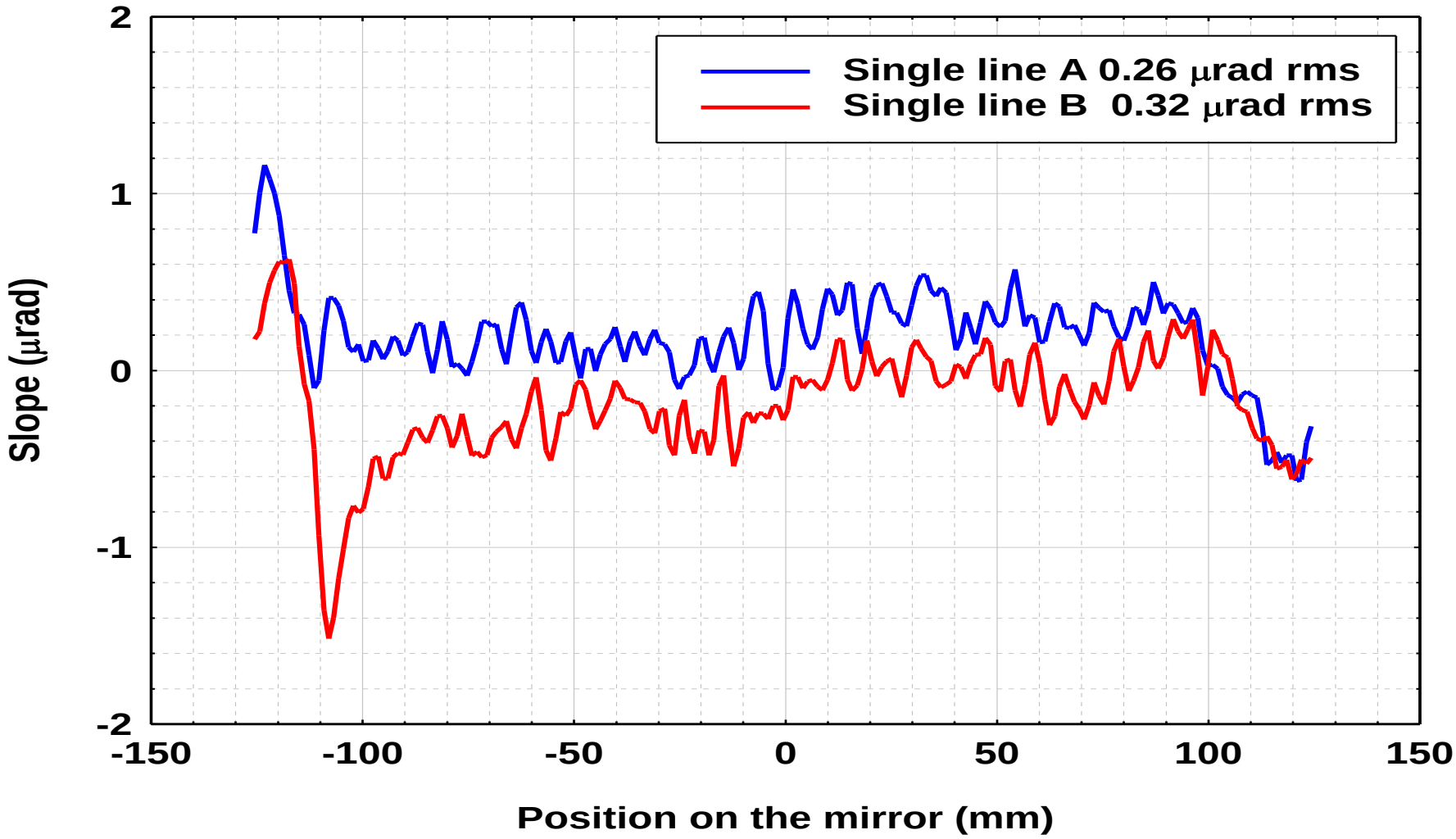
M2A CSX





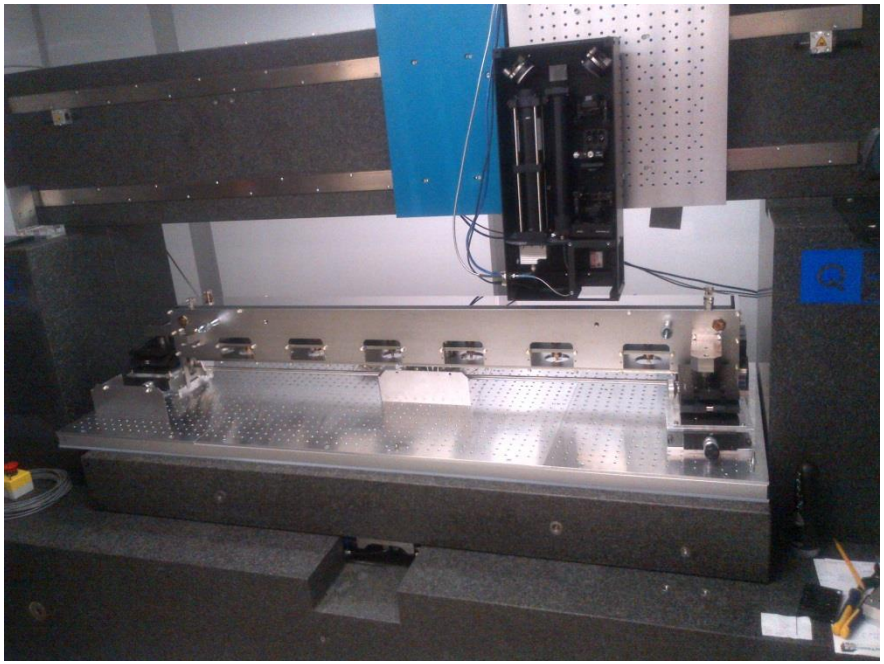
1D Line of Residual slope error of the mirror
and
Integrated PSD

Spherical mirror R~140 m CSX



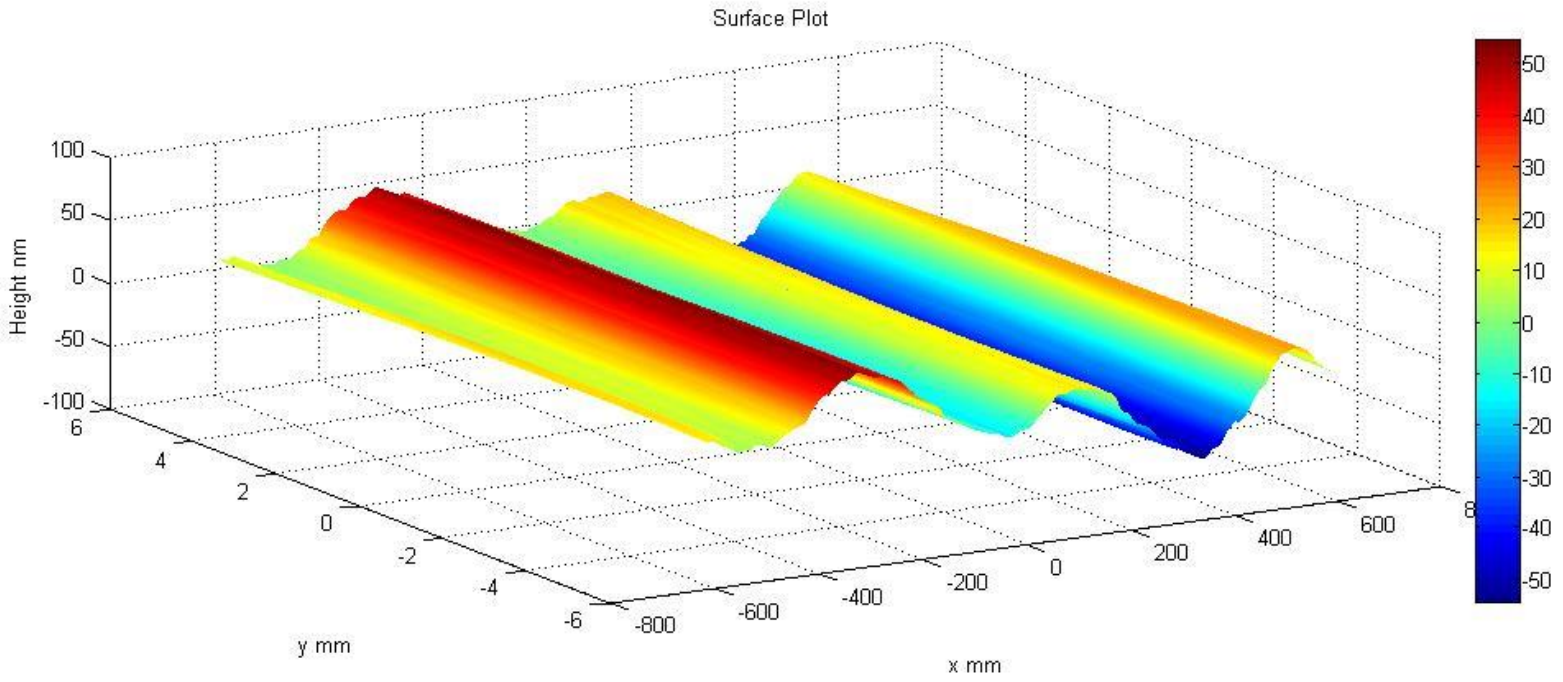
XPD mirror

Lab E5 Mirror preparation



Lab E3 inside the enclosure

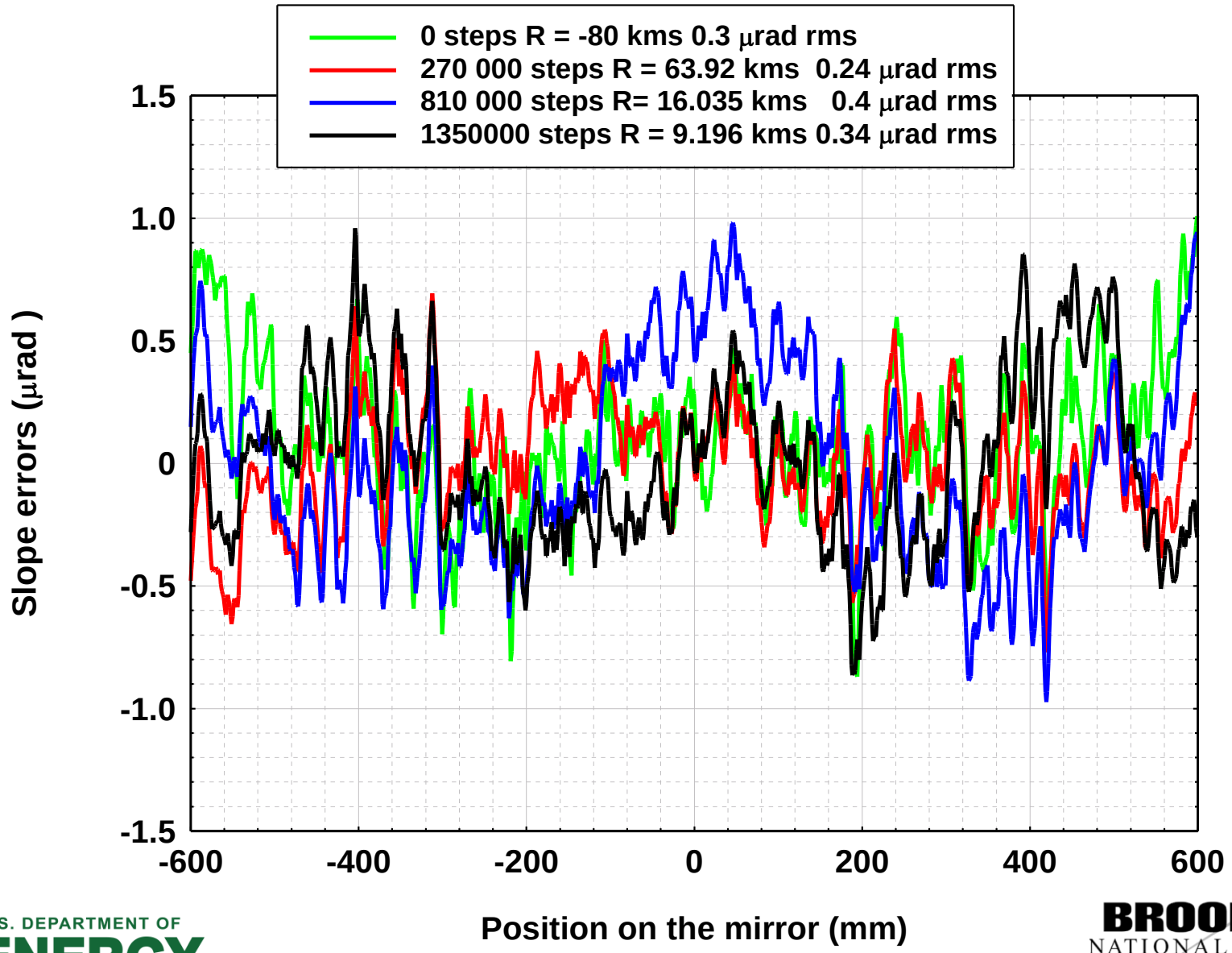
XPD mirror



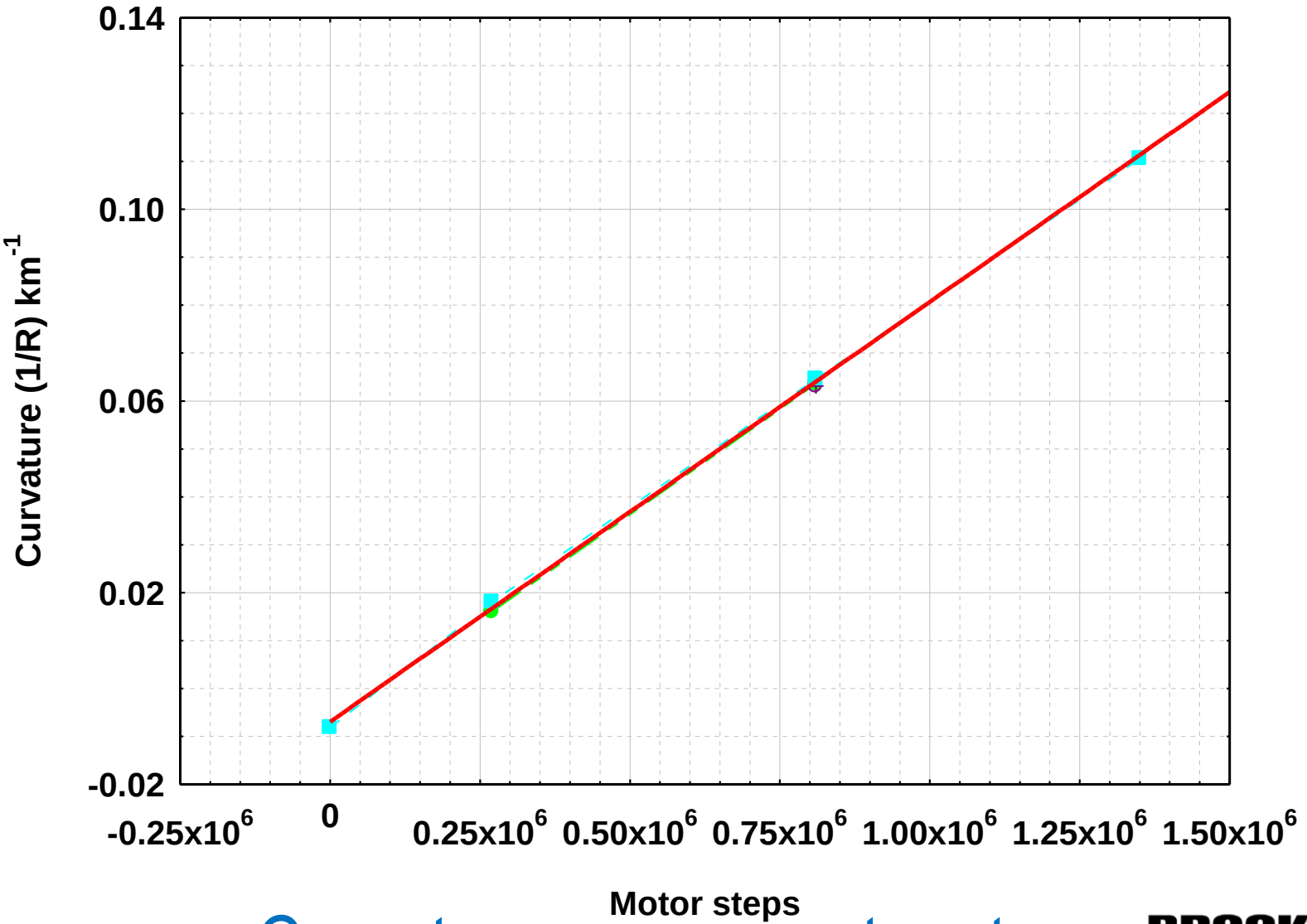
2D Map of Residual slope error of the mirror

(measuring time for 1 scan Forward / Backward ~ less than 3 hours)

XPD mirror

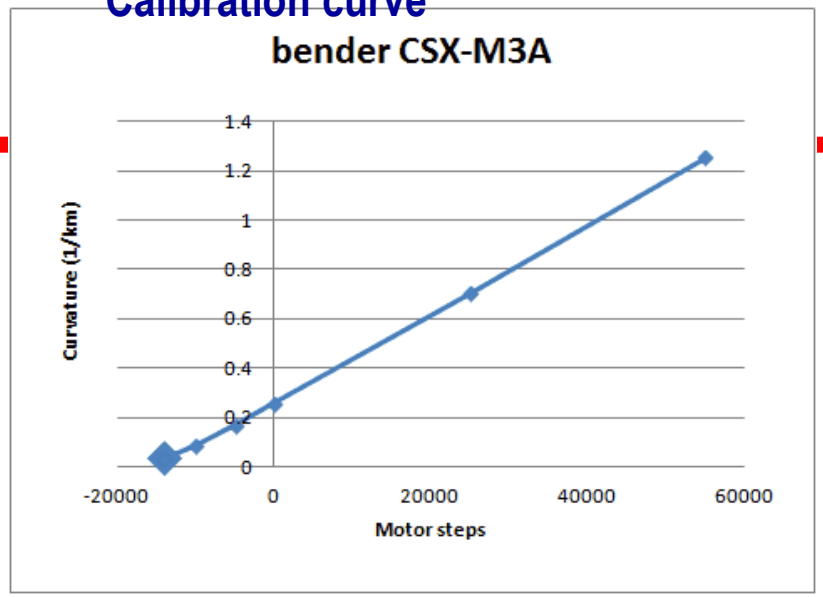

0 steps R = -80 kms 0.3 μrad rms
270 000 steps R = 63.92 kms 0.24 μrad rms
810 000 steps R= 16.035 kms 0.4 μrad rms
1350000 steps R = 9.196 kms 0.34 μrad rms
Slope errors (μrad)
1.5
1.0
0.5
0
-0.5
-1.0
-1.5
-600
-400
-200
0
200
400
600
Position on the mirror (mm)

XPD mirror

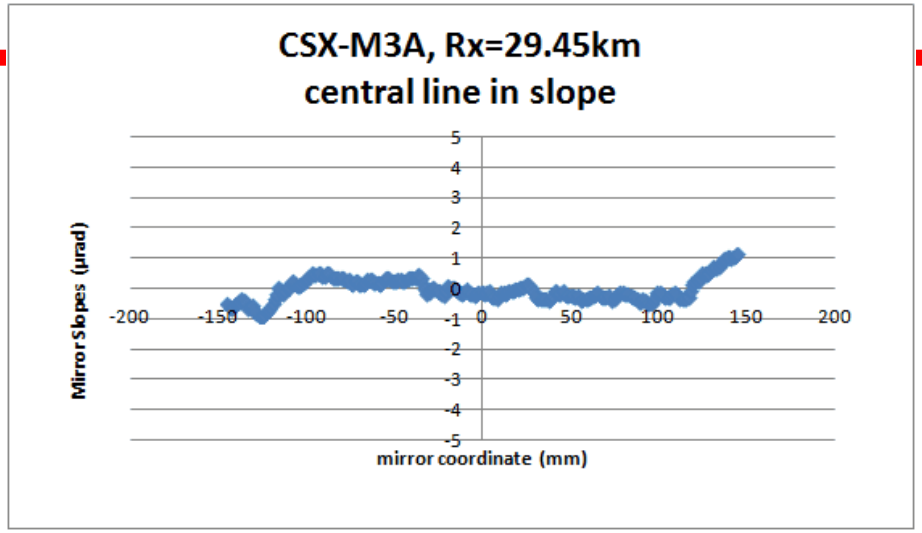


Curvature versus motor steps

Calibration curve

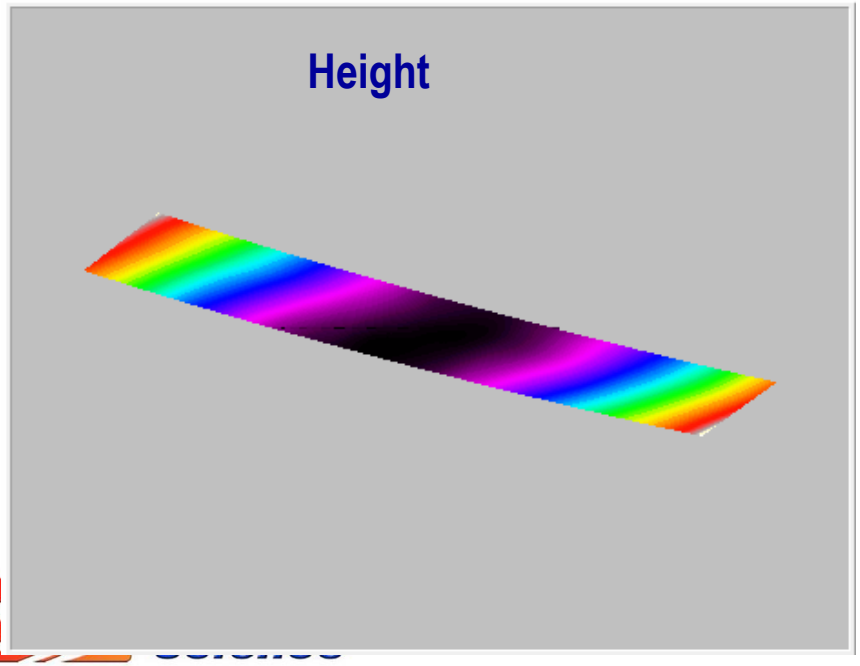


1D residual slope



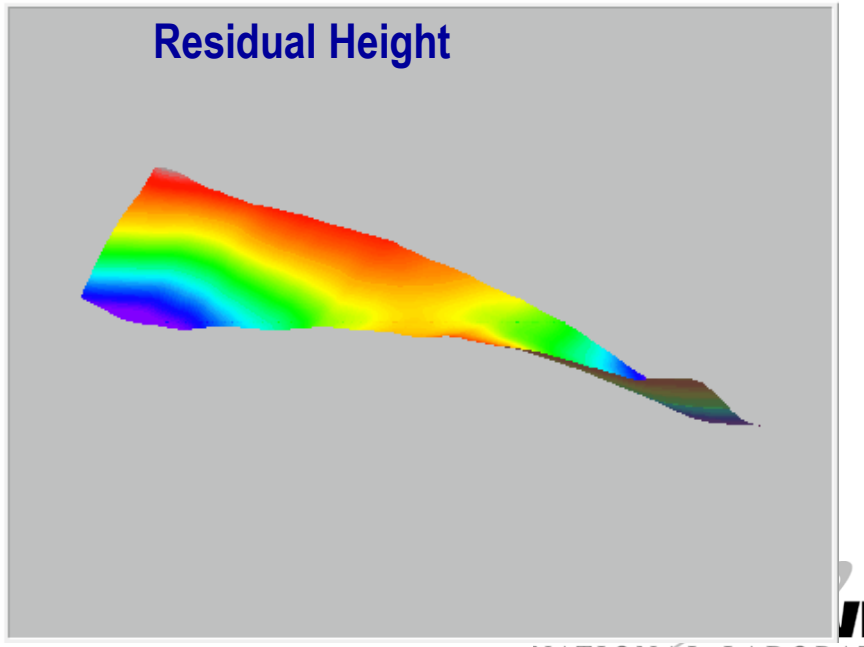
CSX-M3A : -14000 steps, Rx=29.45km

Height

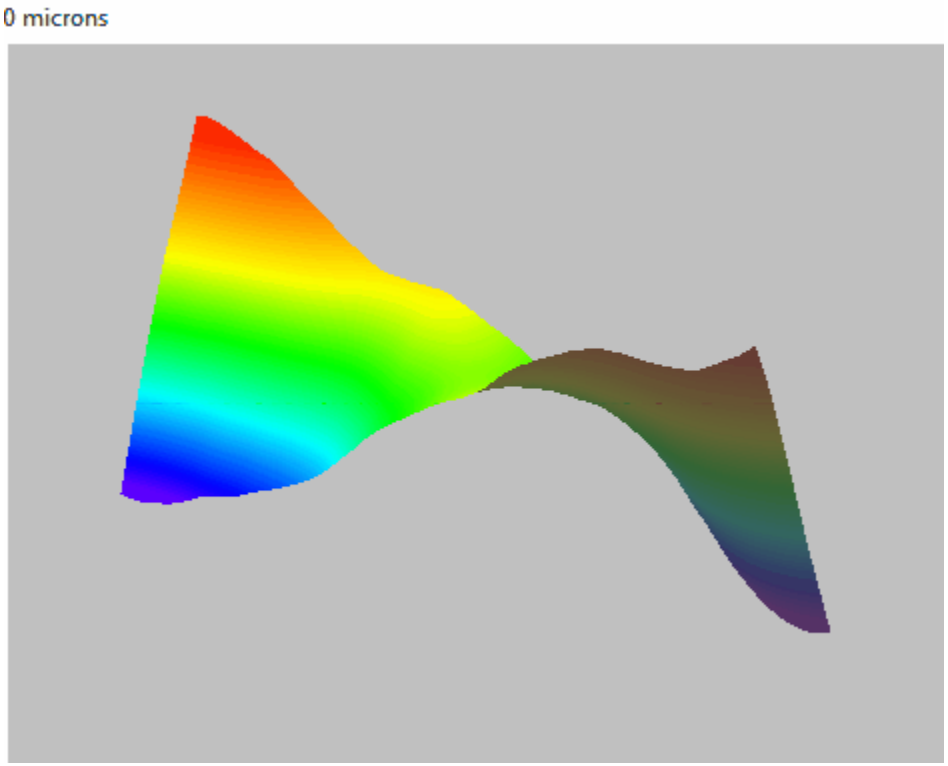


CSX-M3A : -14000 steps, Rx=29.45km

Residual Height



Bendable mirror after shiming

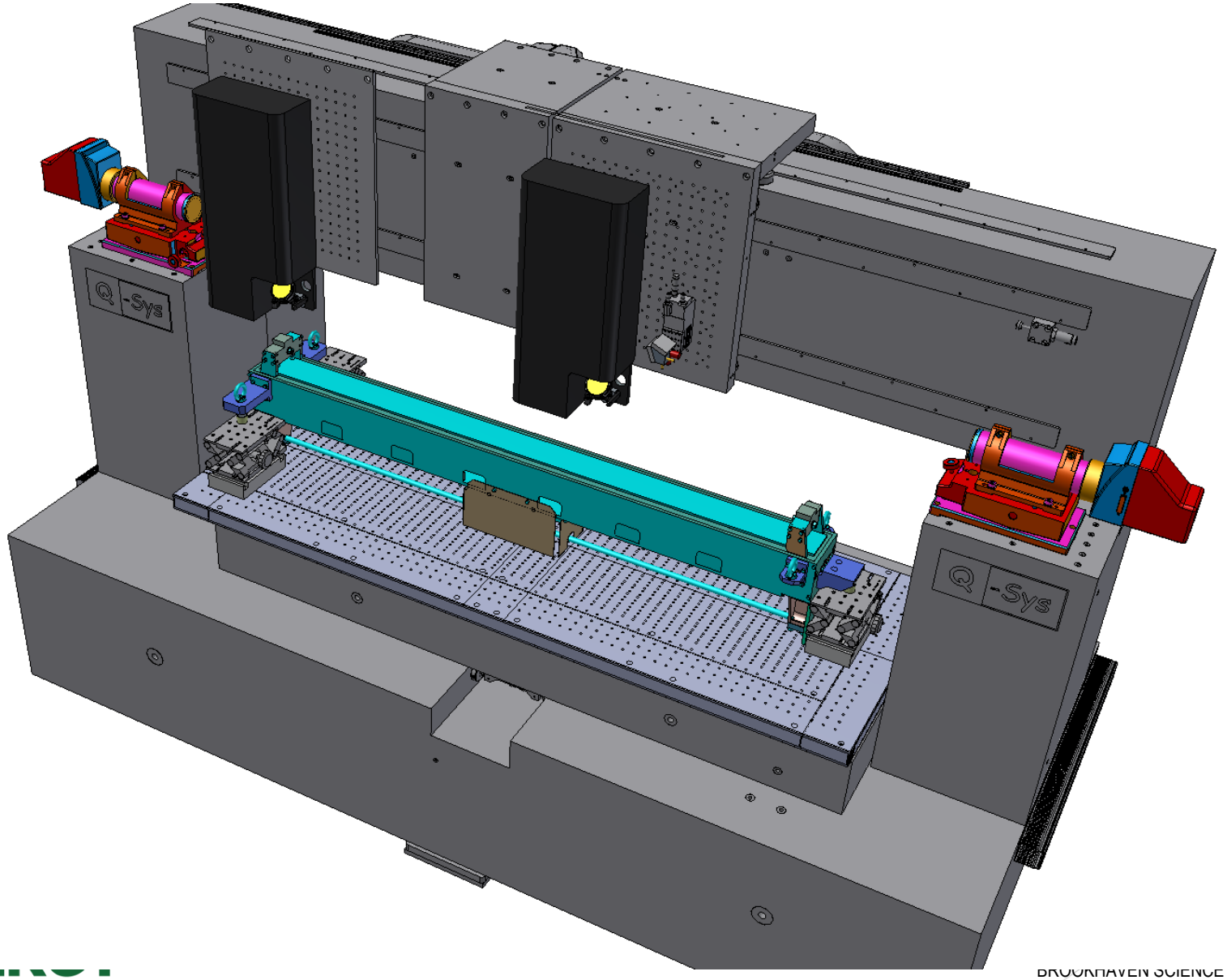


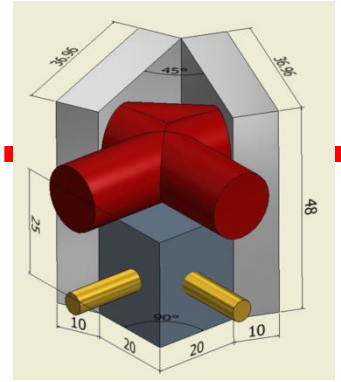
Possible improvements

Depend on *Shutdown and Budget*

Deflectometry based Optical Metrology Station

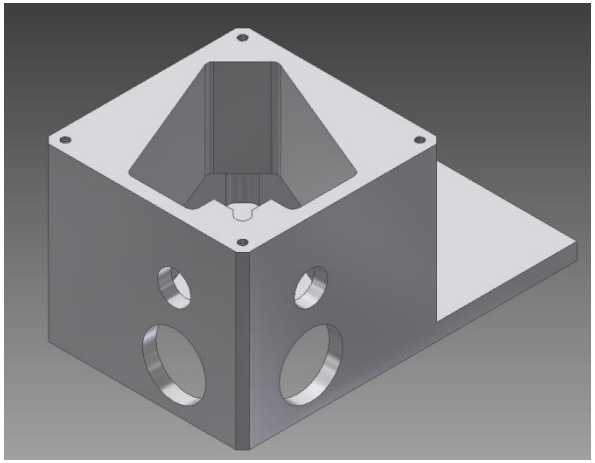
Combine several instruments in the same platform

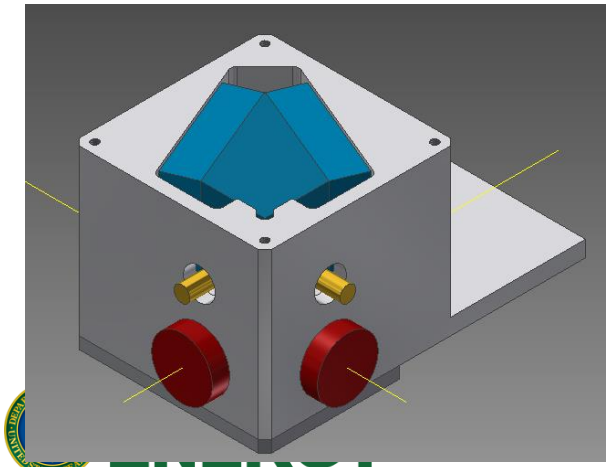




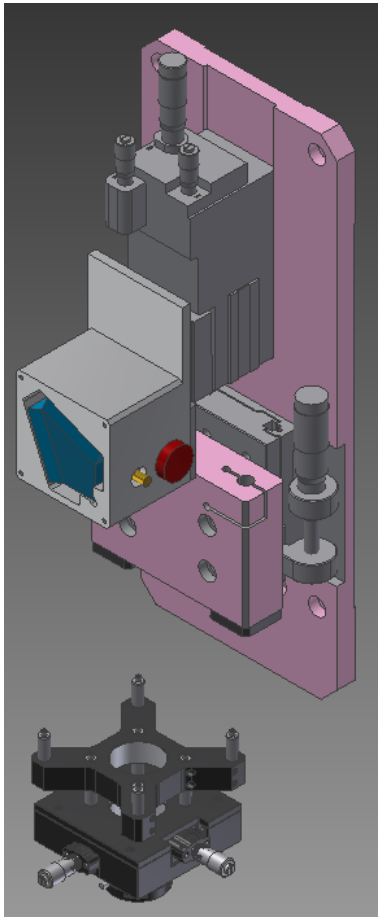
Hollow penta-prism
20 x 20 mm

Optical Head
~ 25 kg

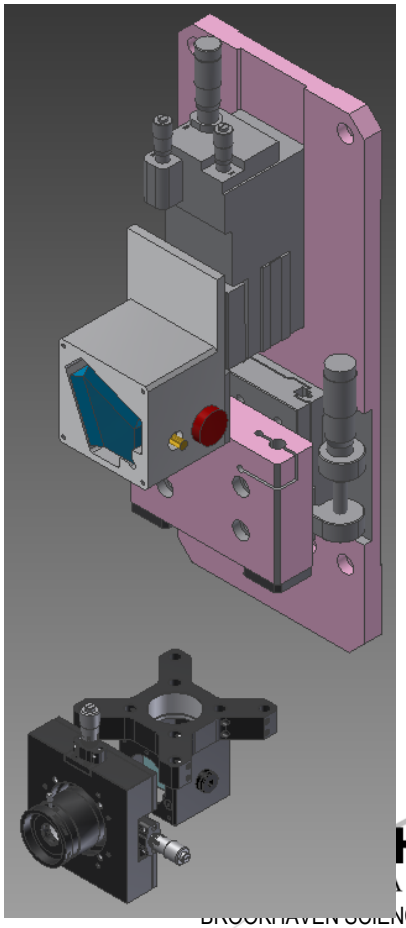




VFM



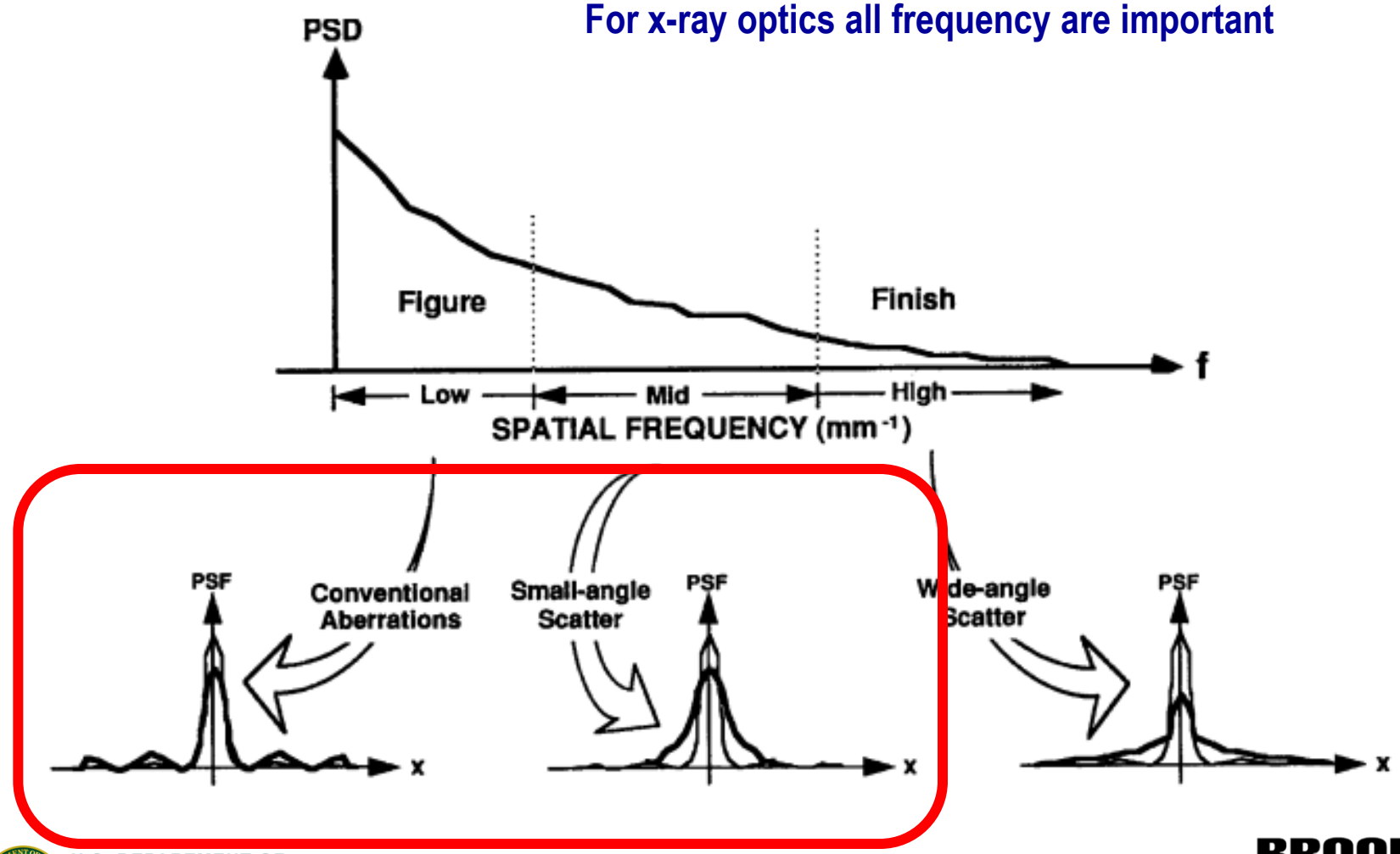
HFM



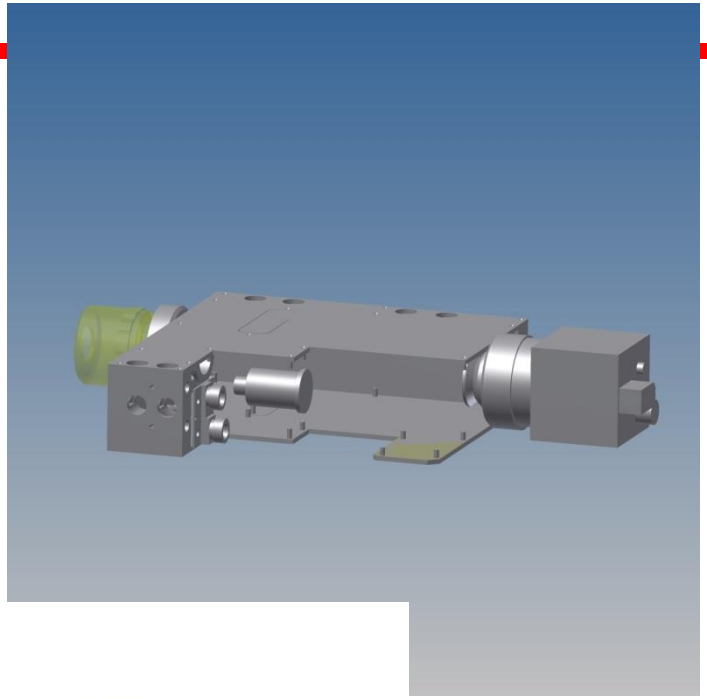
Try to get access to higher spatial resolution

Effect of the surface quality differs on each spatial frequency regime

For x-ray optics all frequency are important

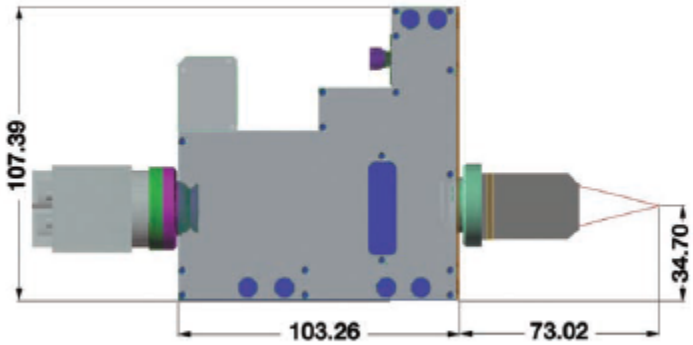


Add another optical head for higher resolution



Specifications

System Type	Portable, high-resolution video microscope
Probe	Phase measuring interferometer
Objectives	10X Nikon Mirau standard; 20X Mirau, or 2.5X Michelson or 5X Michelson optional
Working Distance	2.5X: 10.3 mm; 5X: 9.3 mm; 10X: 7.4 mm; 20X: 4.7 mm
Vertical Range	±6 µm
RMS Repeatability	0.05 nm
RMS Precision	0.1 nm
Sample Reflectivity	4–98%



MFT probe.

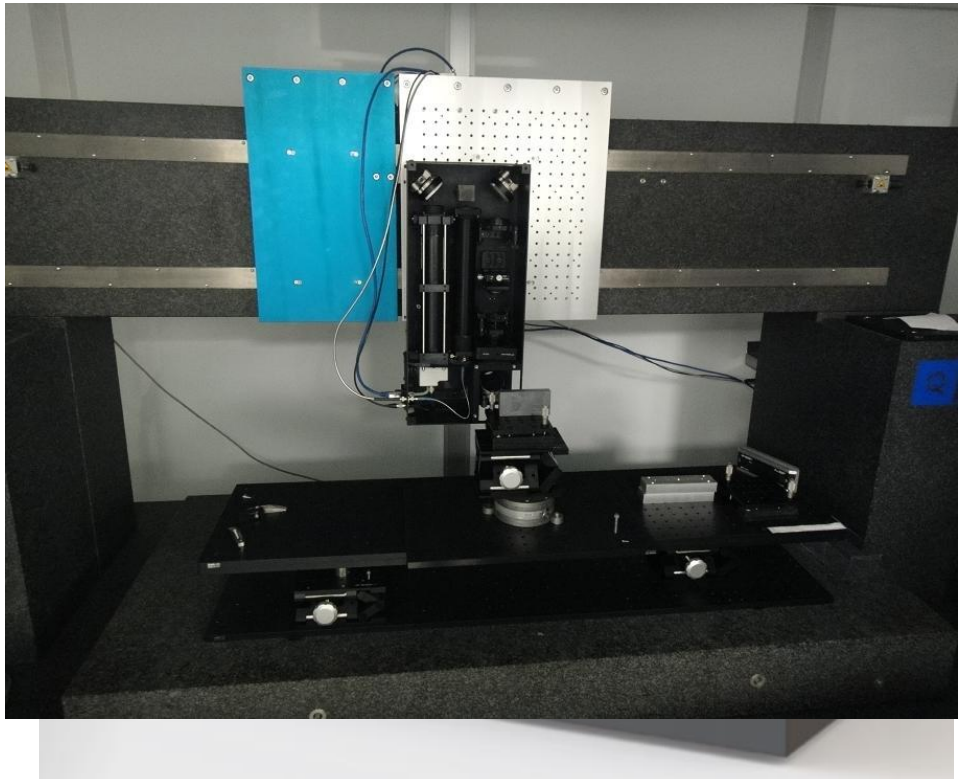
Add another optical head still based on a SH wavefront sensor with higher spatial resolution

Main advantages

- Same measuring points for both instruments
- “Easy” integration in the existing hardware and software
- Try to reach smaller radius of curvature / toroidal mirrors

CONCLUSION

Shack-Hartmann Wavefront sensor	
Number of points	15 x 11
Pupil size	18 x 13 mm
Microlenses size Resolution	1.2x1.2 mm²
Measurement range	From 5 mm to 1500 mm
Radius of curvature	From -1.2 m to 1.2 m
Sensitivity	Better than 50 nrad rms



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EUROSTARS PROJECT 13202

Q-Sys

eurostars™

Imagine Optic

New high accuracy surface metrology platform

System for high quality mirror characterization

Slope accuracy better than 50 nrad rms

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