The European XFEL deformable optics project

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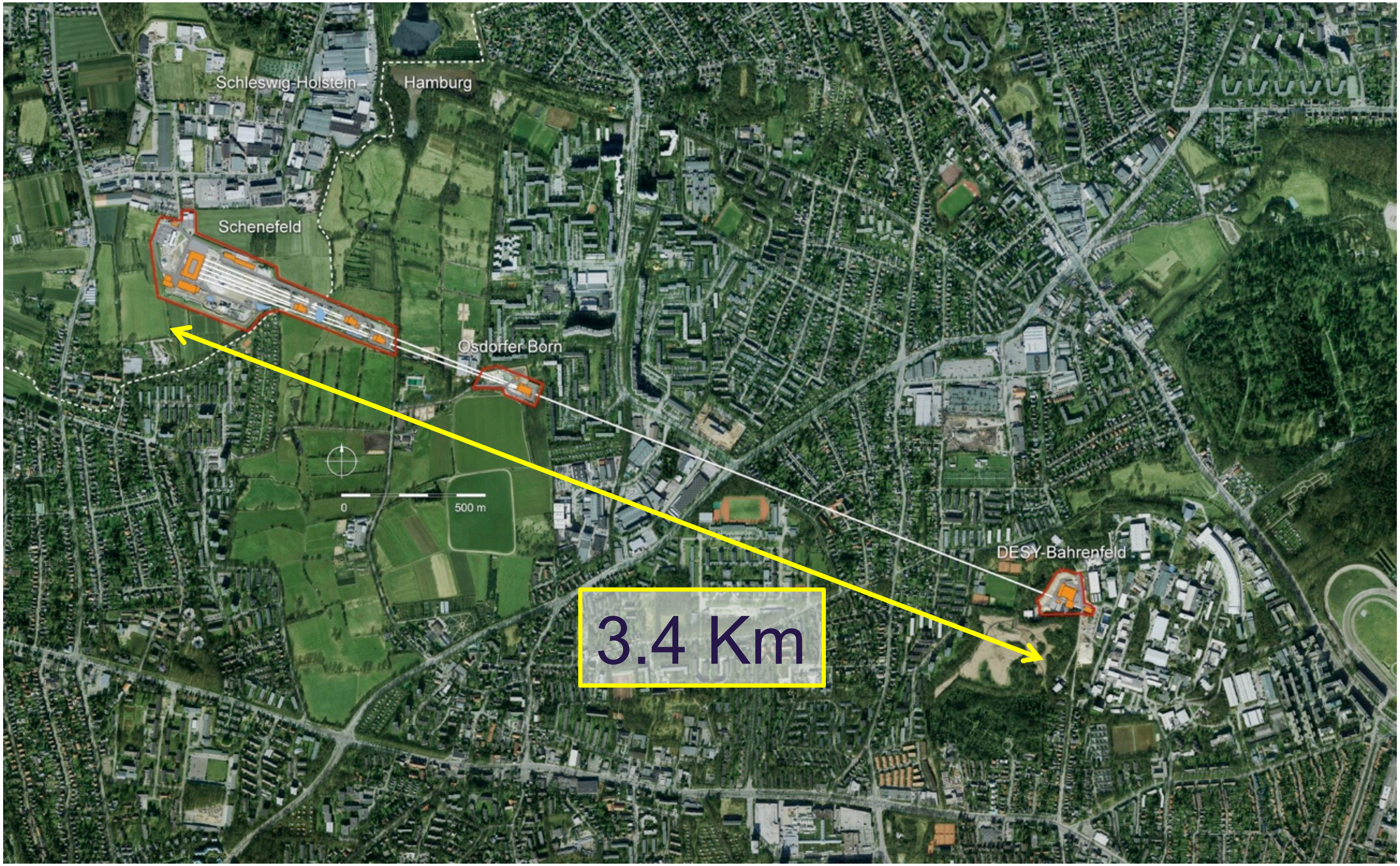
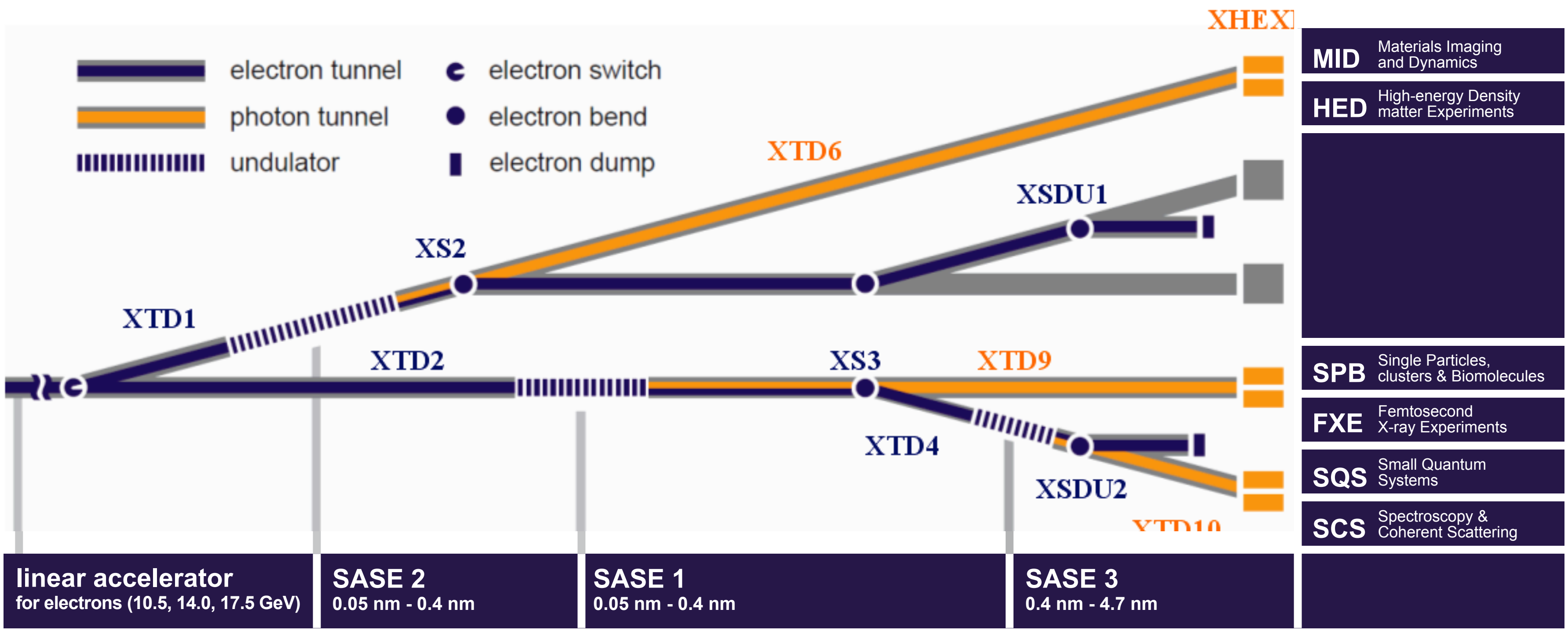
Overview of the European XFEL project



Overview of the European XFEL project

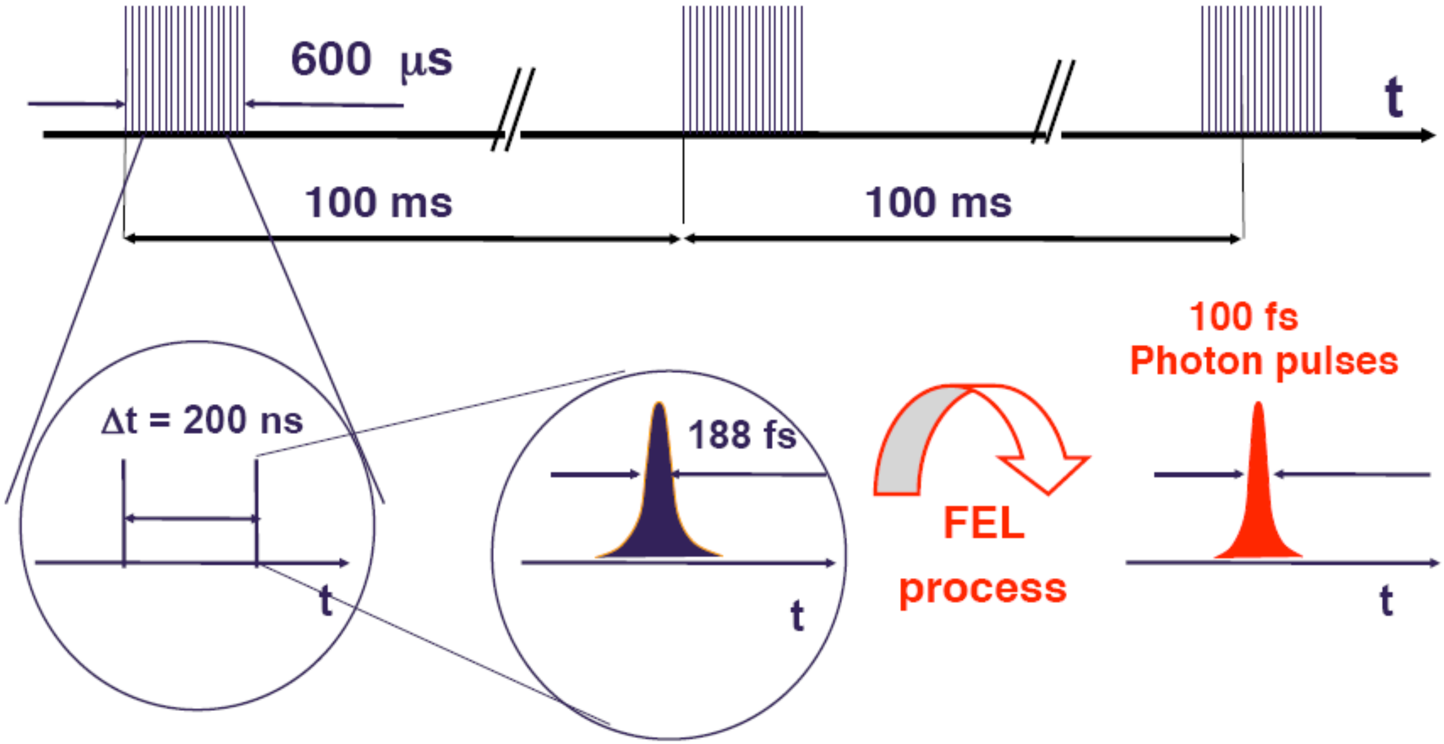
Overview of the European XFEL project

Undulator Segment	FEL radiation energy [keV]	Wavelength [nm]
SASE 1	3 - over 24	0.4 - 0.05
SASE 2	3 - over 24	0.4 - 0.05
SASE 3	0.27 - 3	4.7 – 0.4



Overview of the European XFEL project

Up to 27000 pulses every second
(2700 pulses / 10 Hz)

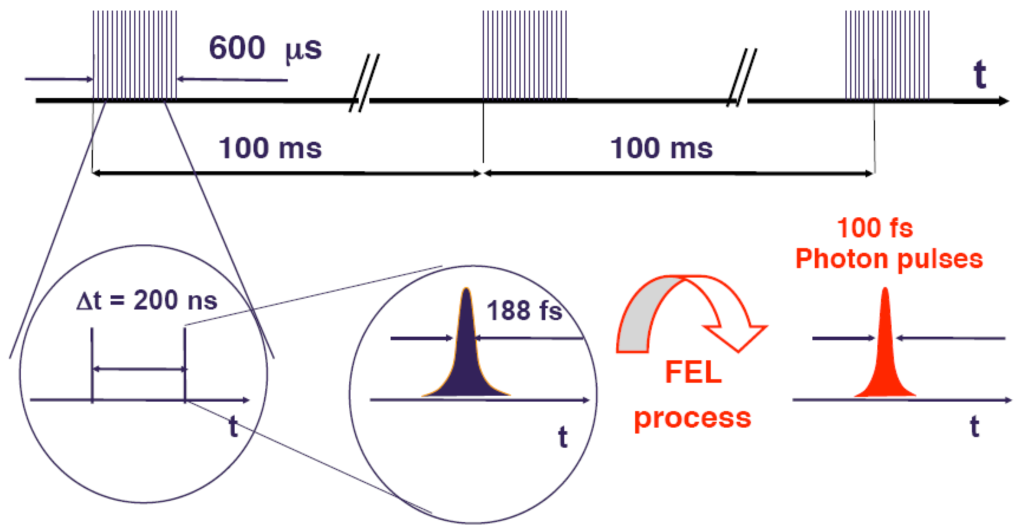


Thermal effect on offset mirror

M. Altarelli et al., The XFEL Technical Design Report, 2006

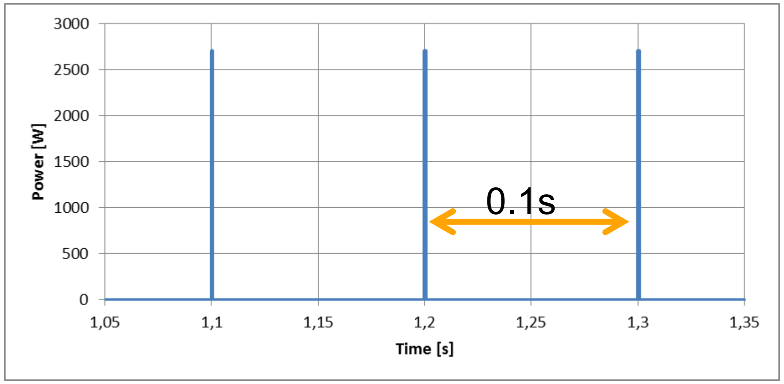
Pulse time structure:

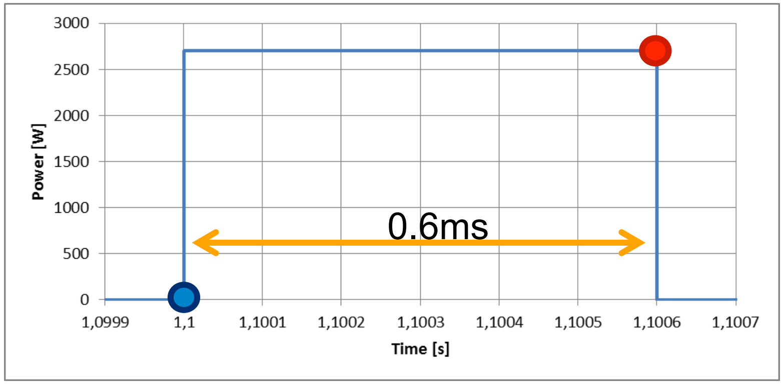
- # pulses / train = 2700
- Pulse train duration = 0,6ms
- Pulse train rep. rate = 10Hz



Assuming 10mJ as pulse energy:

- P_{pulse} = 100GW
- P_{train} = 45kW
- P = 270W

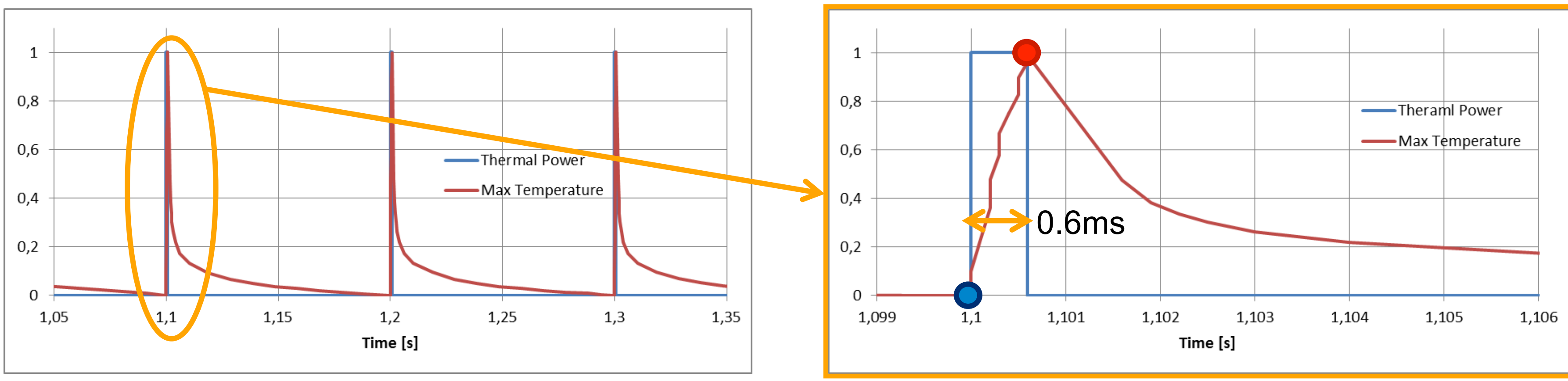




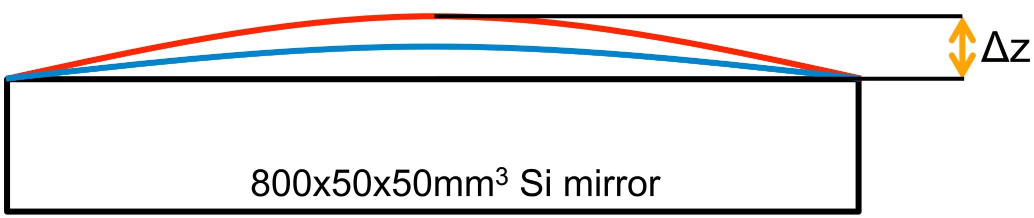
Thermal effect on offset mirror

(Simulations by Daniele La Civita and Antje Trapp)

Max temperature variation (ΔT_{max}=0.3-0.6ºC)

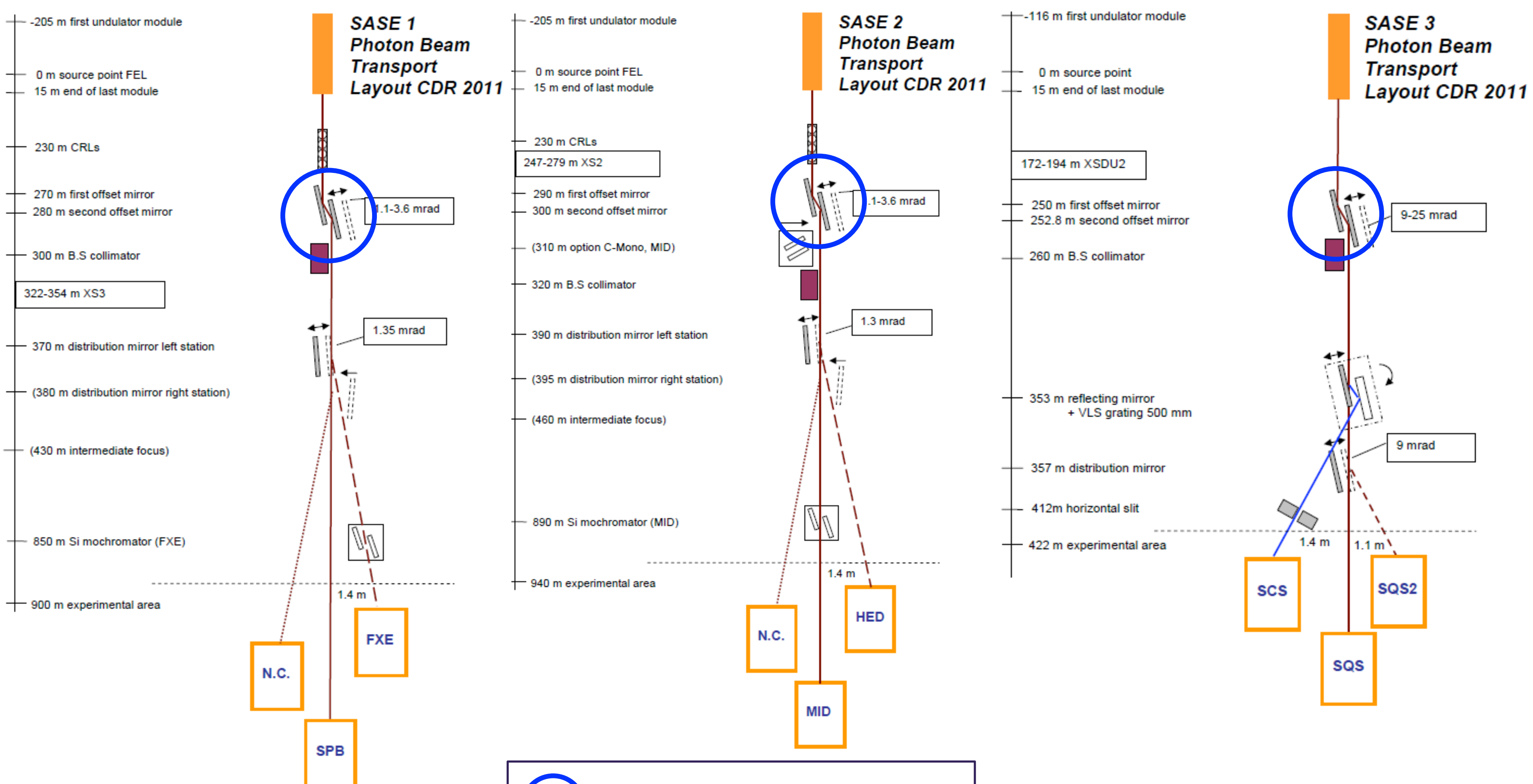


Dynamic thermal bump @ 10Hz



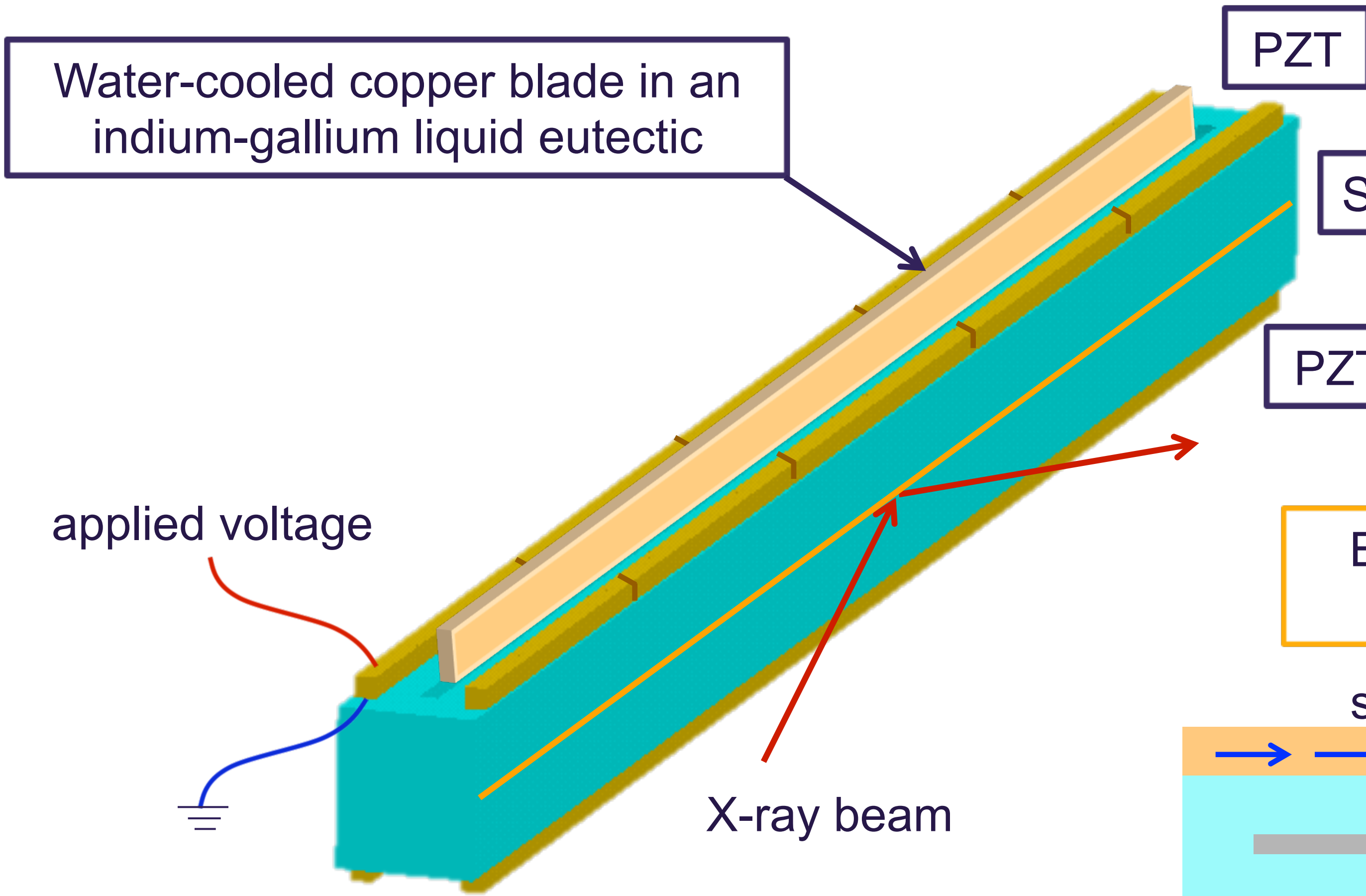
	Δz
Peak	18-33 nm
Average	15-29 nm

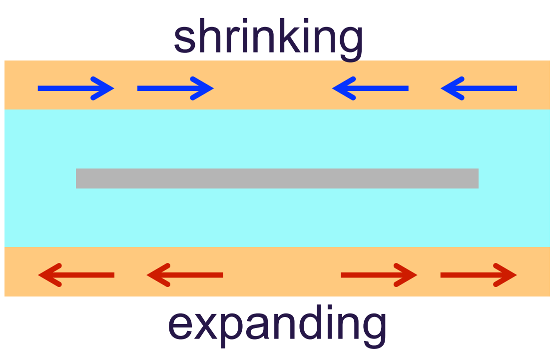
Bendable Mirrors in the Distribution System



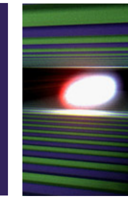
= Bendable mirror

Bendable Mirror design





General Specification



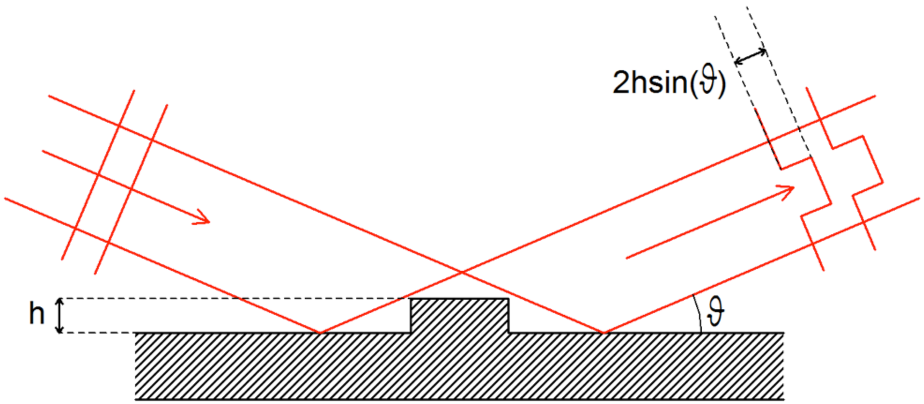
	Mirror specifications	Prototype specifications
Substrate length	930 mm	950 mm
Optical surf (mer x sag)	800x20mm^2	750x20mm^2
Substrate Material	Single crystal silicon	Single crystal silicon
Surface coating	B_4C	none
Figure	Flat	Flat
Cooling system	InGa eutectic bath	Groove present but not used

Height error (Peak to Valley) (4th order polynomial removed)	<2 nm	<20 nm
Slope error (root mean square)	<0.05 urad <0.5 urad sagittal	<1 urad <0.5 urad (3rd order removed) <5 urad sagittal
Roughness (@10x) rms	<0.3 nm	<0.3 nm
Radius of curvature	>600 km	>50 km >1 km sagittal
Bending capability	-50 km to flat to +50 km	-50 km to flat to +50 km

Wavefront distortion

Wavefront preservation depends on:

- Mirror length → diffraction on mirror edges
- Residual height errors



$$h_{rms} < \frac{1}{28}\frac{\lambda}{sen\theta} \approx \frac{1}{28}\frac{\lambda}{\theta}$$

$$\varphi = \frac{2h\sin\theta}{\lambda}$$

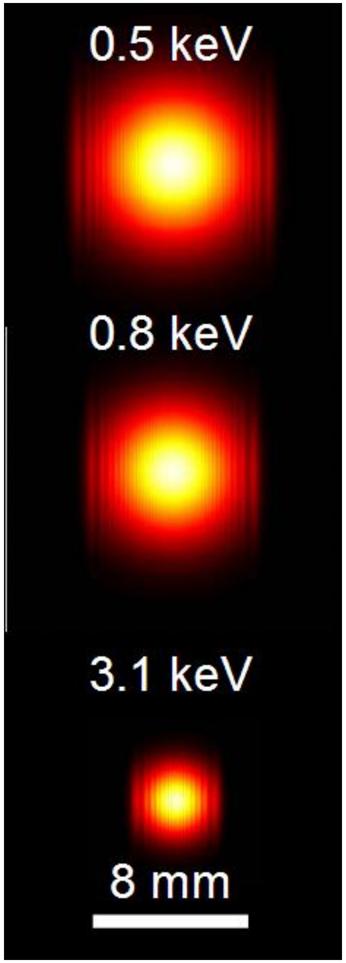
$\varphi_{rms} \leq \frac{1}{14}$ Maréchal criteria

φ : phase error

θ : "grazing" incidence angle

λ : beam wavelength

h : P-V error



Sinn, Samoylova, et al., "X-ray Optics and Beam Transport CDR", April 2011 and F. Siewert et al., Optics Express **20**, 4525, (2012)

General Specifications

- Why so long ?

To allow 4-sigma cutting and operation in different conditions/energies/footprint

To minimize thermal load over the surface

- Why so “flat” ?

To reduce wavefront aberrations (fully coherent beam!)

- Why bendable ?

To correct for the different beamlines length. To correct offset mirrors thermal load.

To correct low spatial frequency aberrations on the surface

- Why InGa cooled ?

To allow mirror cooling without clamping (=bending)

- Why B4C coated ?

To protect the mirror from beam damage (eventual misalignment and misfocusing)

Prototype manufacturing

Substrate preparation + Standard polishing

Ion Beam polishing + Internal Metrology

Metrology at BESSY (HZB)

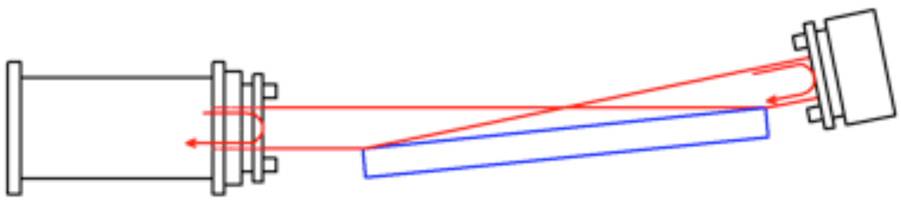
Today

Advanced polishing (EEM) + Internal Metrology

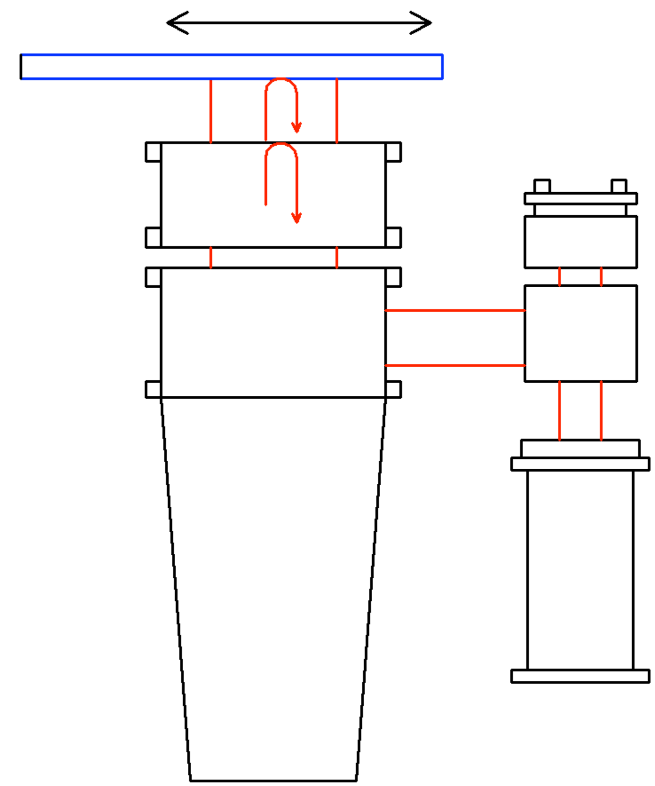
Final Metrology at BESSY (HZB)

Internal Metrology (THALES-SESO)

Two different methods using Fizeau interferometry:



Grazing Incidence Setup

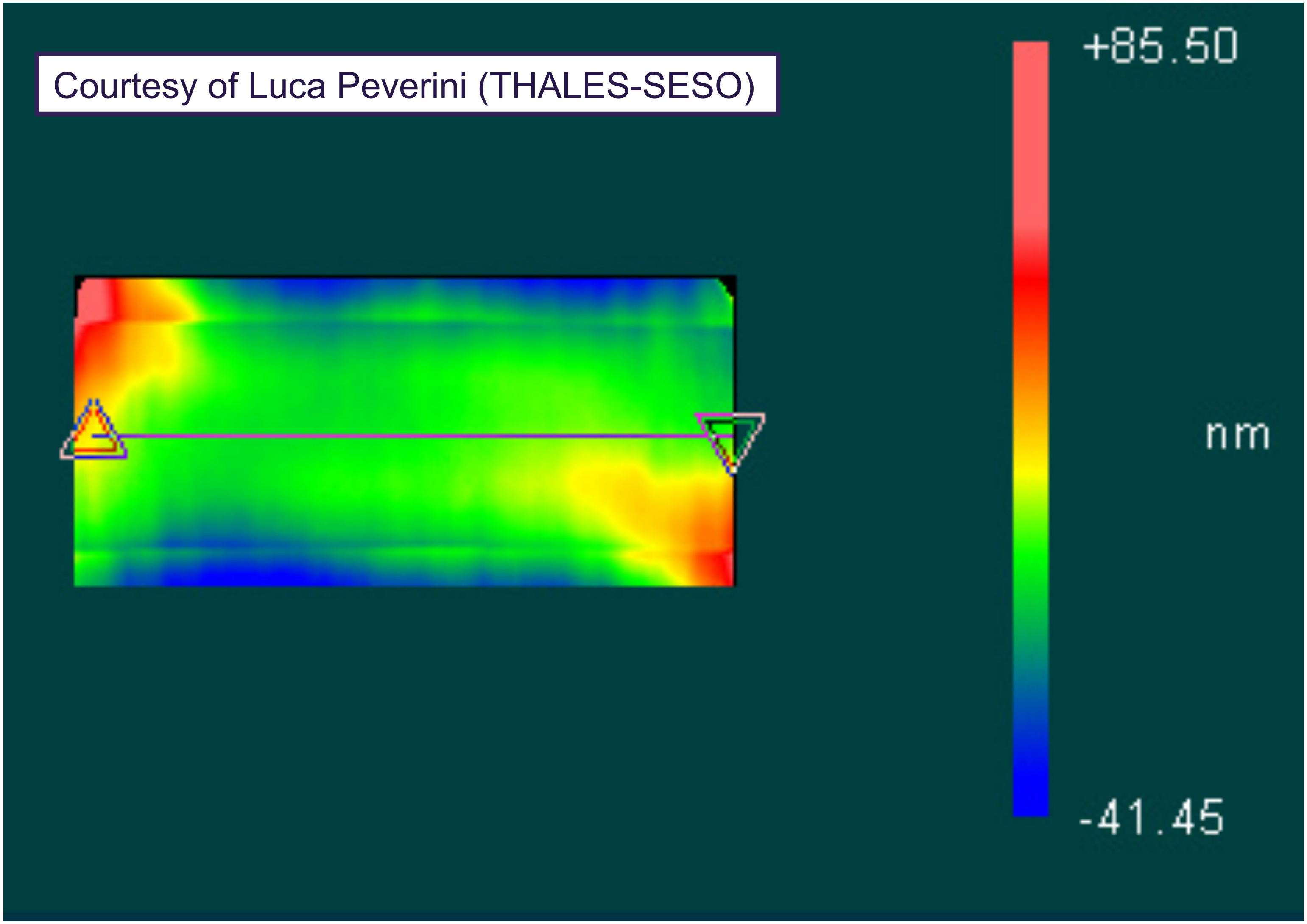


Normal Incidence/Stitching Setup

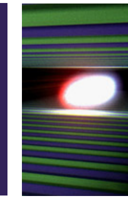
Pros:
- Direct height profile measurement
- Full Map measurement
- High spatial resolution
- Fast (=seconds)

Cons:
- Limited by Reference Flat Calibration

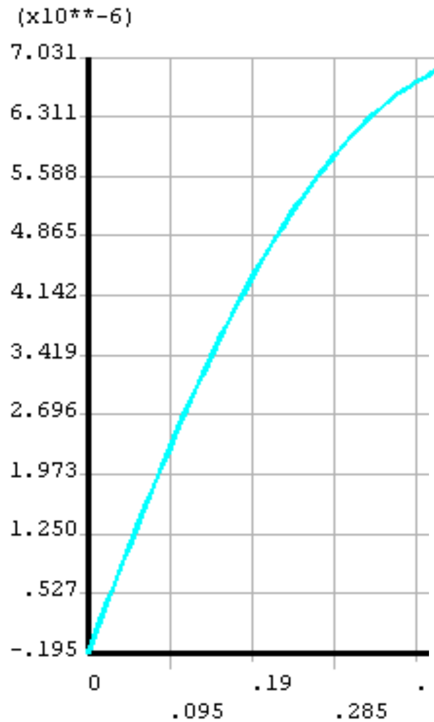
Full surface measurement (THALES-SESO)

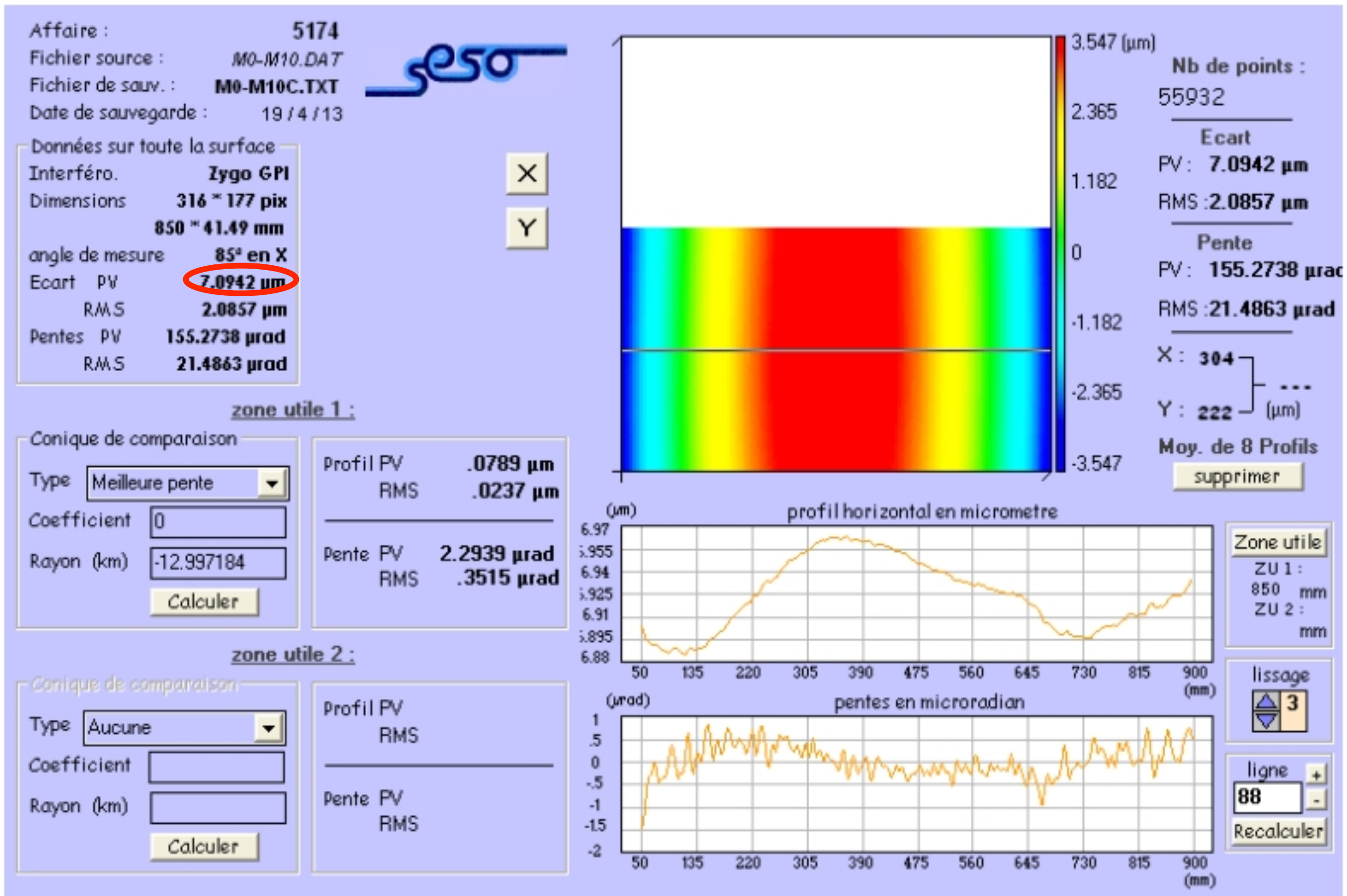


European XFEL



Simulations V.S. Measurements



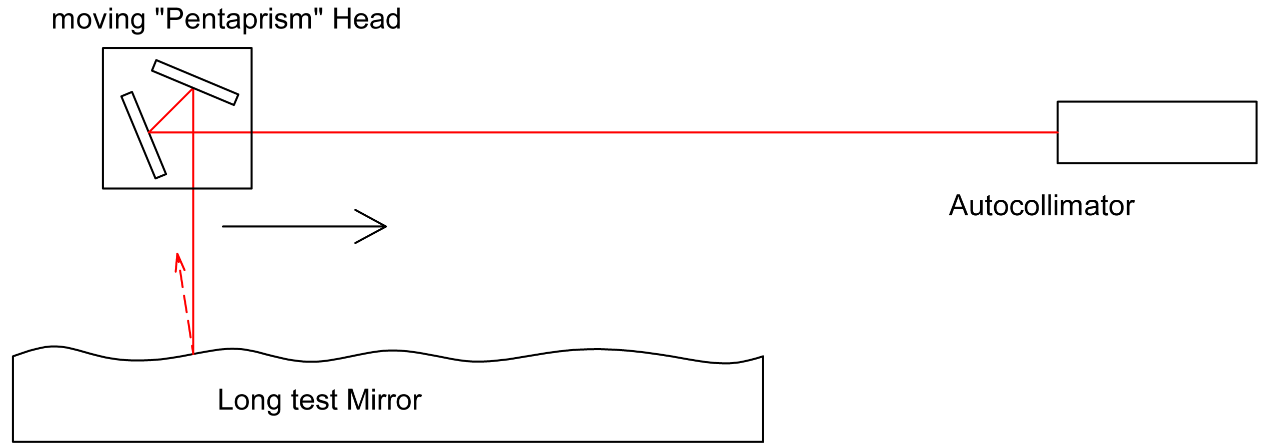


Simulations by Fan Yang

BESSY Metrology (Frank Siewert, HZG)

Deflectometric method:

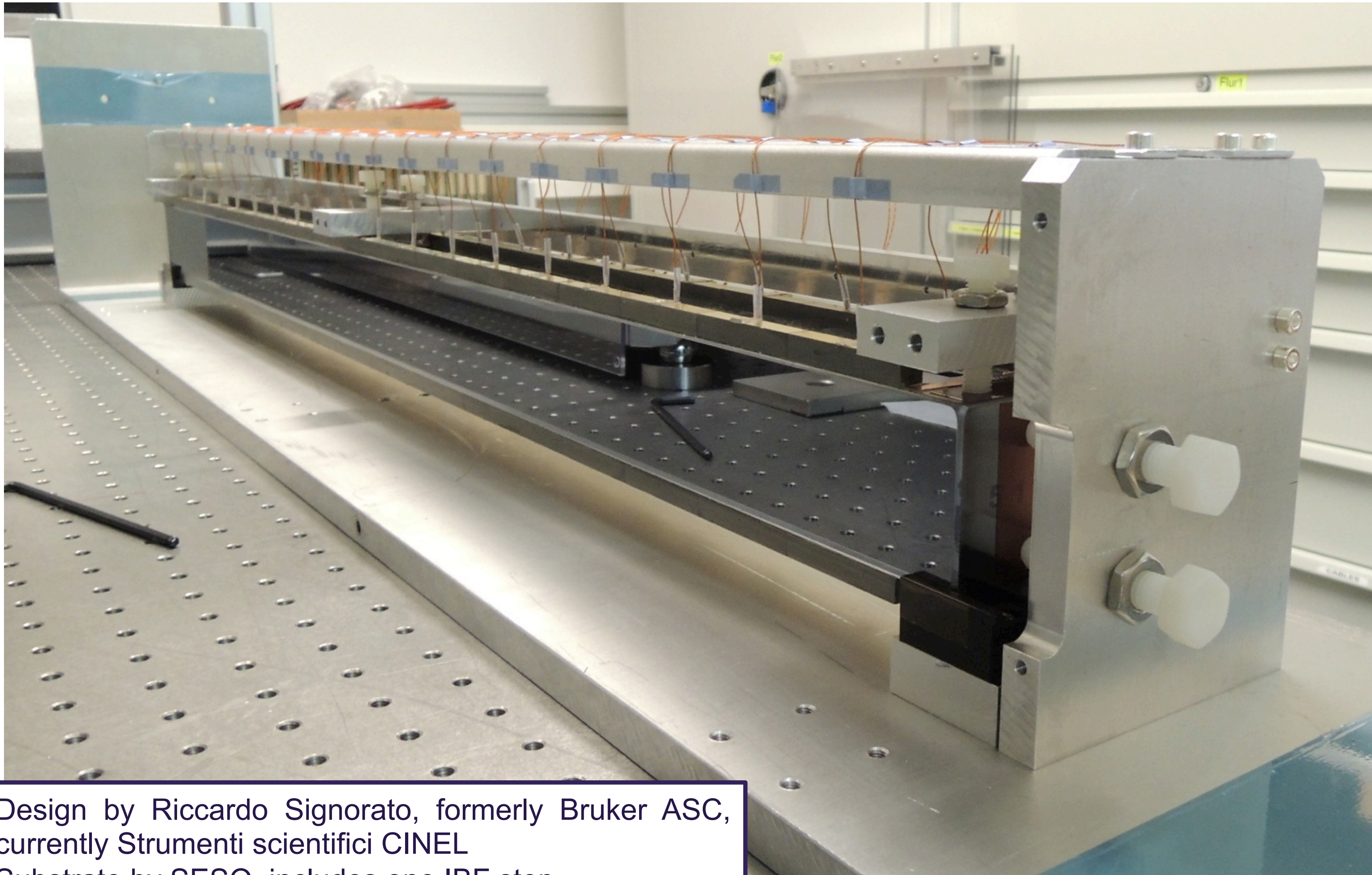
"NOM" Setup



Pros:
- No reference needed
- System already calibrated

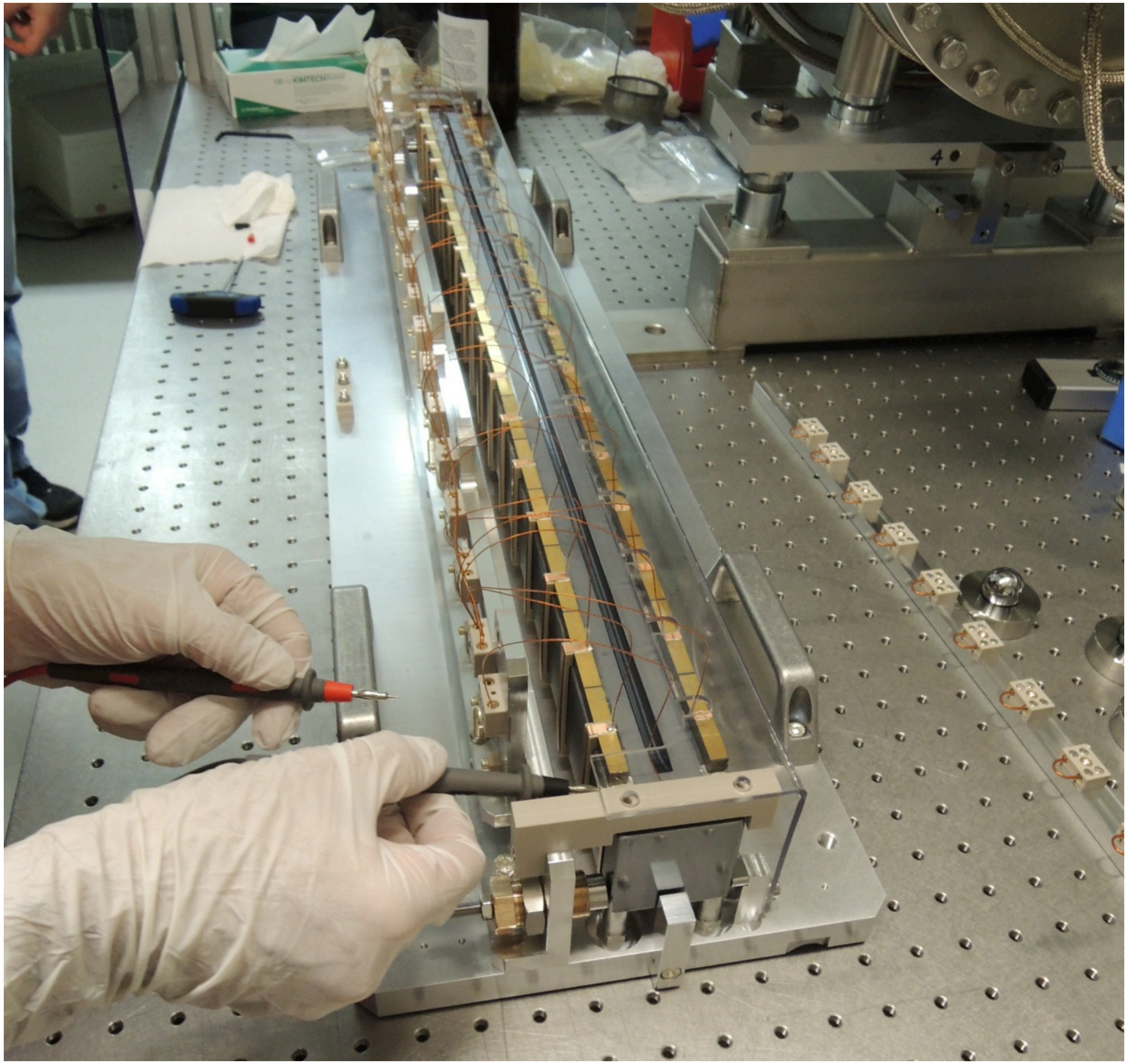
Cons:
- Slope measurement (=indirect height profile measurement)
- "Slow" (=minutes)
- Limited to a profile in its basic implementation (but with BESSY-NOM, slope mapping is possible)

Prototype built by Bruker/CINEL/SESO



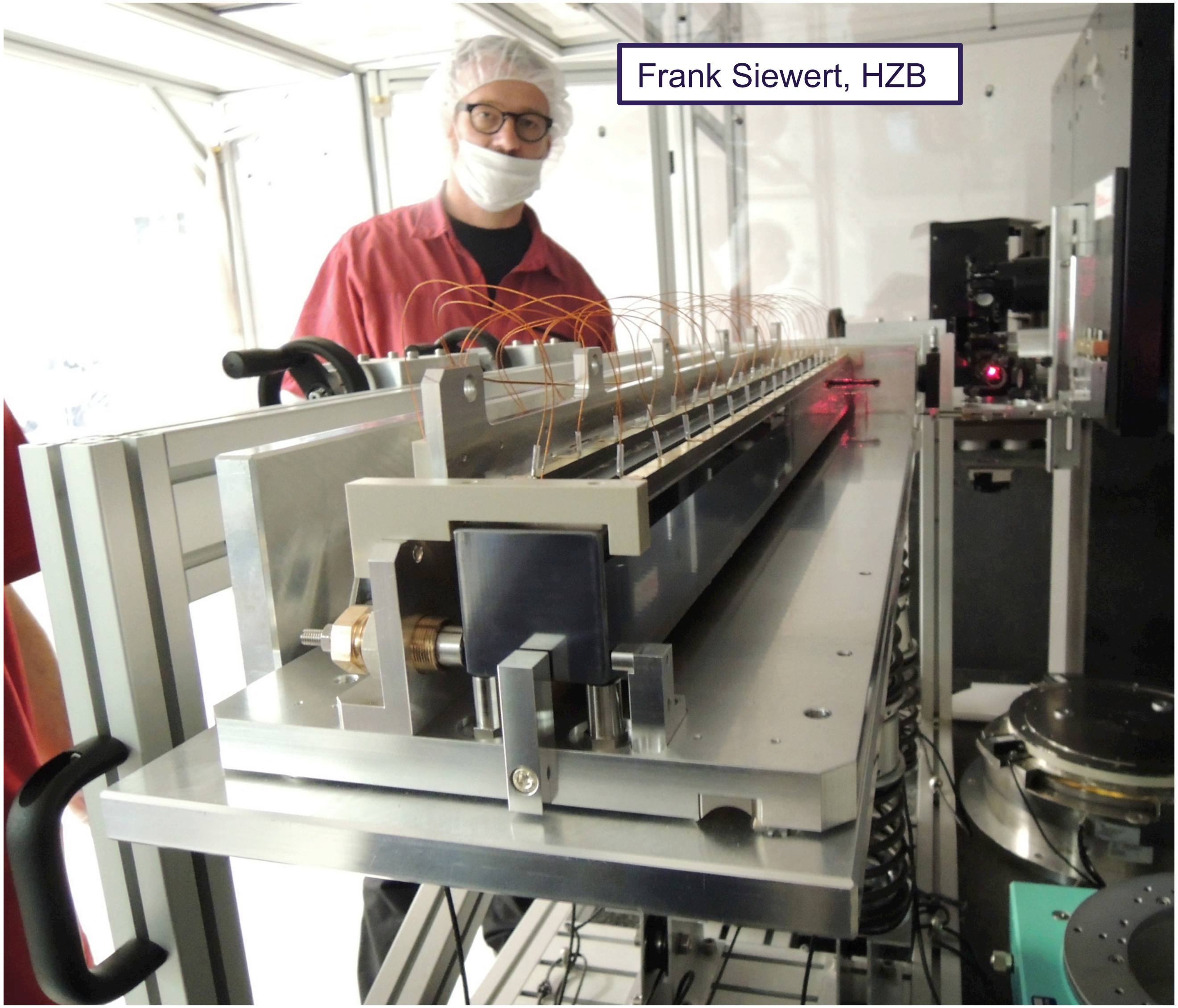
Design by Riccardo Signorato, formerly Bruker ASC, currently Strumenti scientifici CINEL
Substrate by SESO, includes one IBF step

Prototype built by Bruker/CINEL/SESO



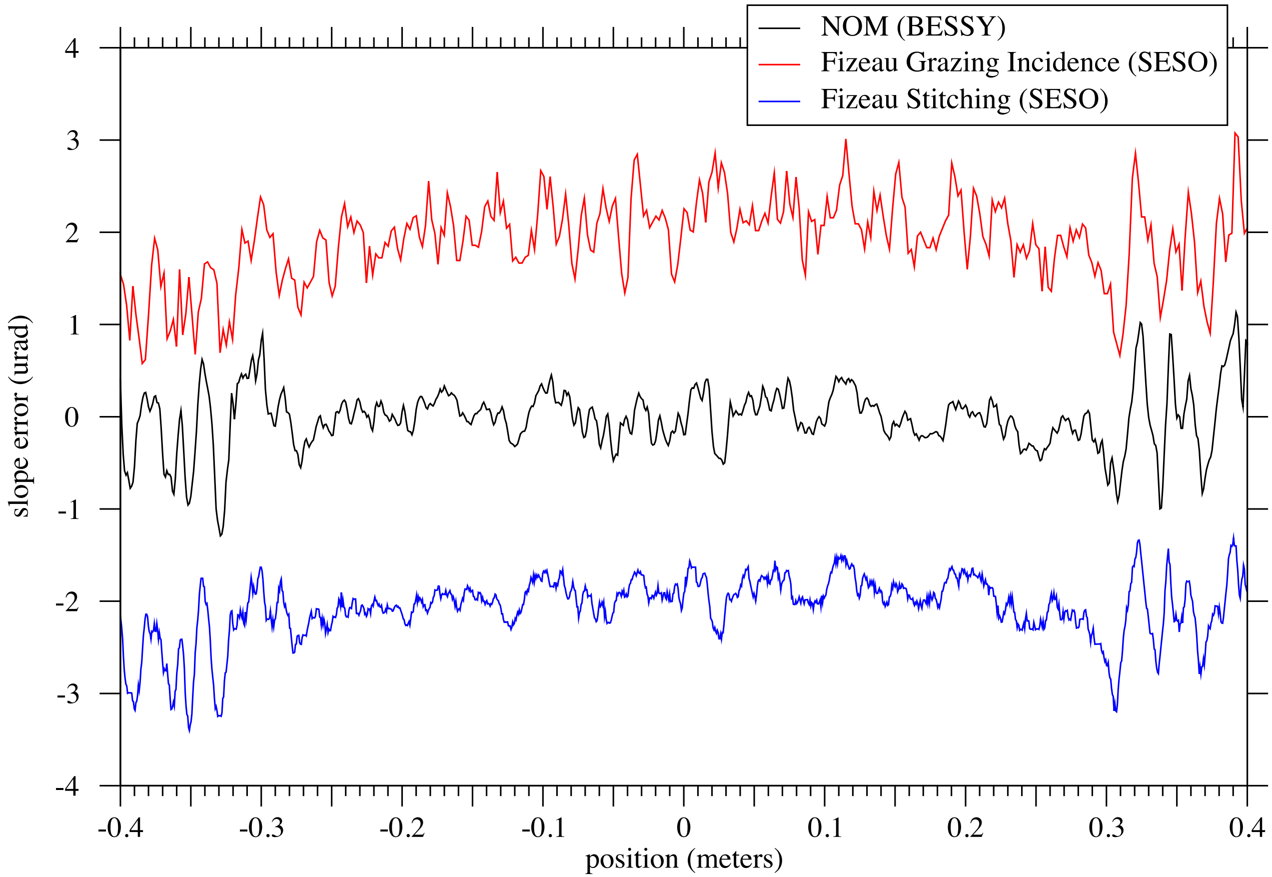
Hands of Riccardo Signorato

Measurements with NOM, BESSY



Metrology results

Residual slope error

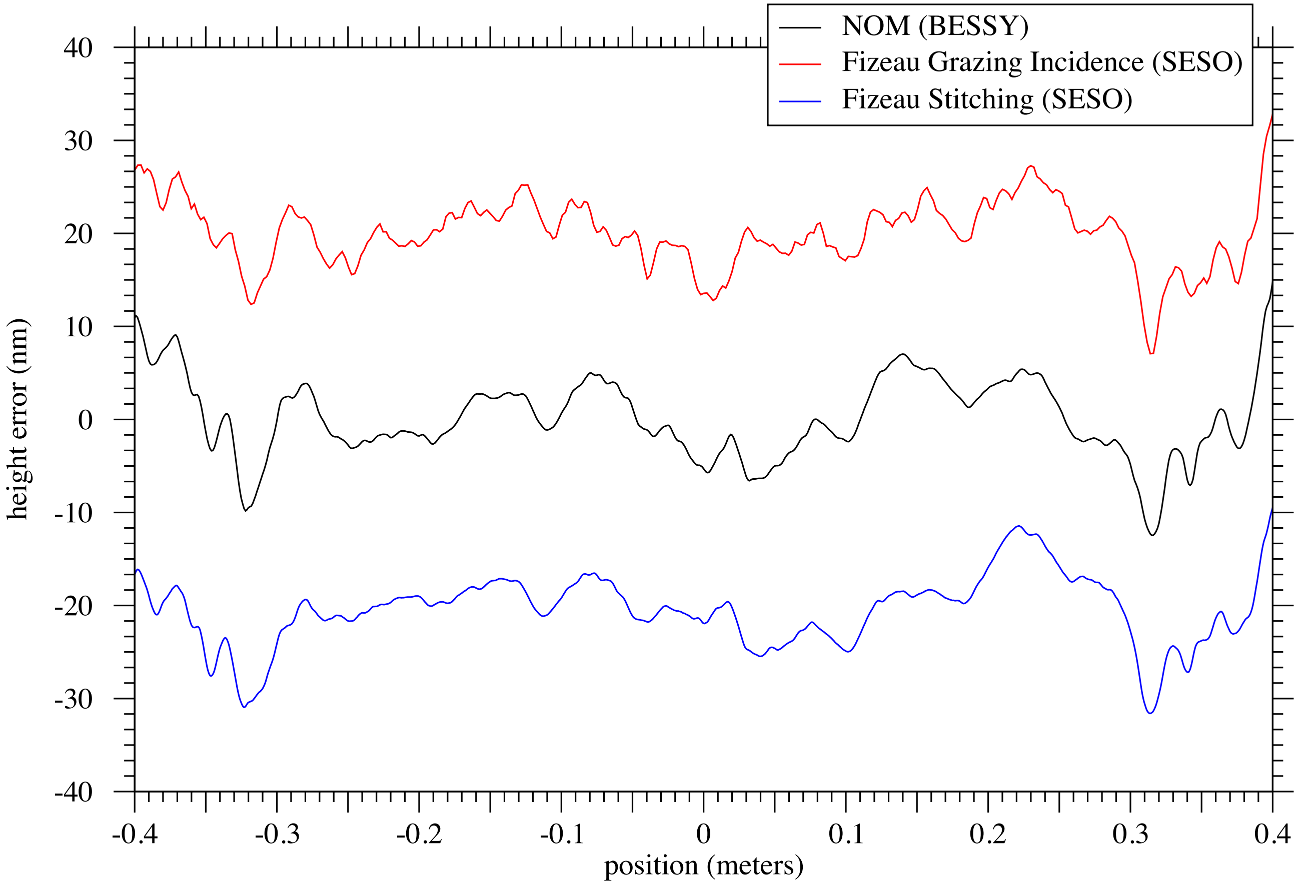


RMS residual slope error:

- NOM (BESSY): 0.317 urad
- SESO (Grazing Incidence): 0.345 urad
- SESO (Stitching): 0.319 urad

Metrology results

Height error profile
(3^{rd} order correction)

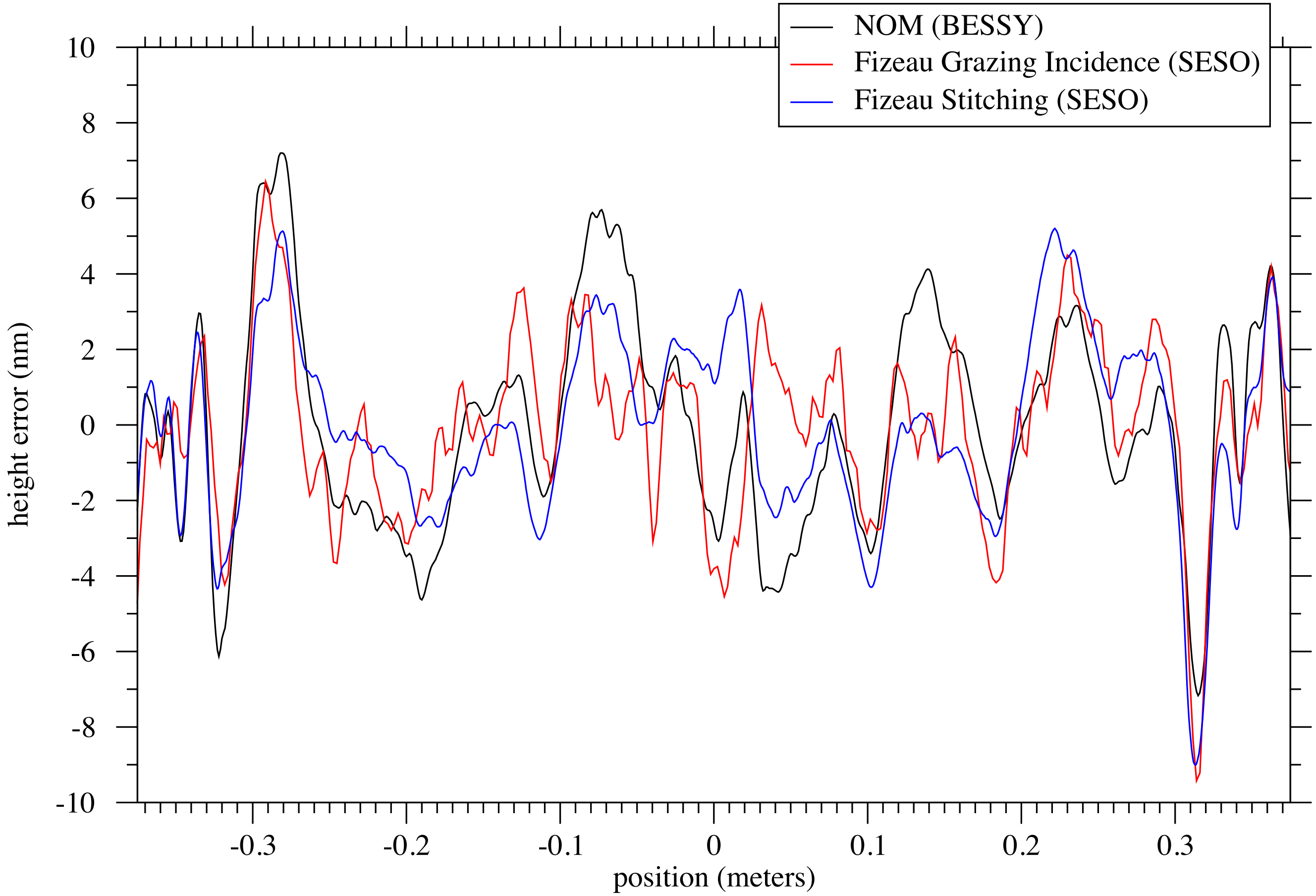


RMS height error (3^{rd} order correction):
- NOM (BESSY): 3.8 nm
- SESO (Grazing Incidence): 3.2 nm
- SESO (Stitching): 3.6 nm

P-V height error (3^{rd} order correction):
- NOM (BESSY): 18.7 nm
- SESO (Grazing Incidence): 18.0 nm
- SESO (Stitching): 18.8 nm

Metrology results

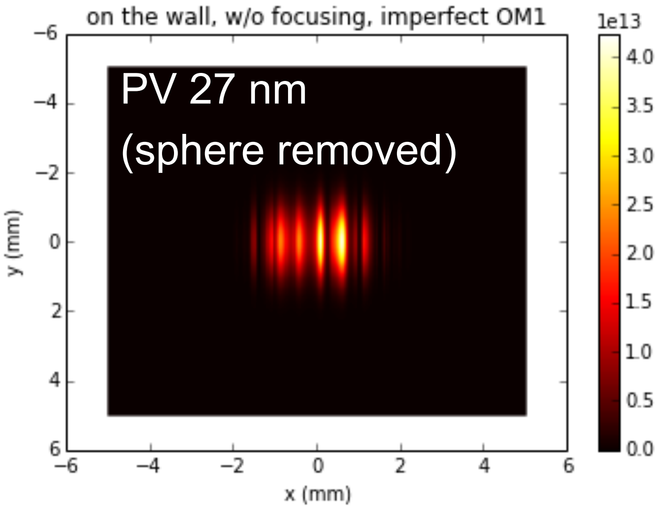
Height error profile
(6^{rd} order correction)

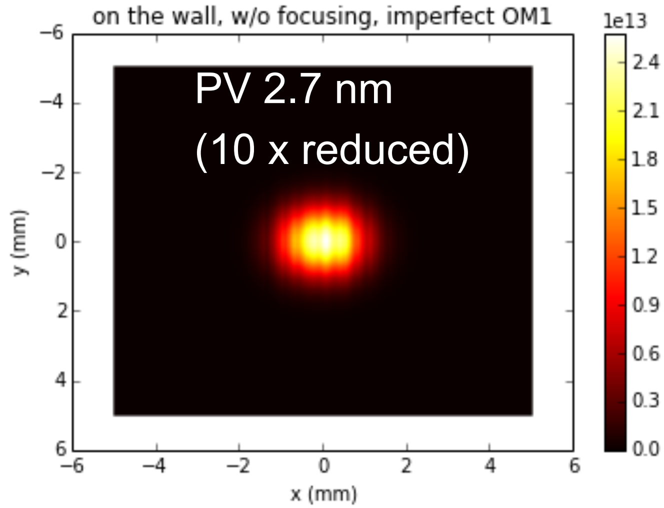


RMS height error (6^{rd} order correction):
- NOM (BESSY): 2.8 nm
- SESO (Grazing Incidence): 2.3 nm
- SESO (Stitching): 2.4 nm

P-V height error (6^{rd} order correction):
- NOM (BESSY): 14.4 nm
- SESO (Grazing Incidence): 15.9 nm
- SESO (Stitching): 14.2 nm

How would the prototype perform at E.XFEL?





Calculations by

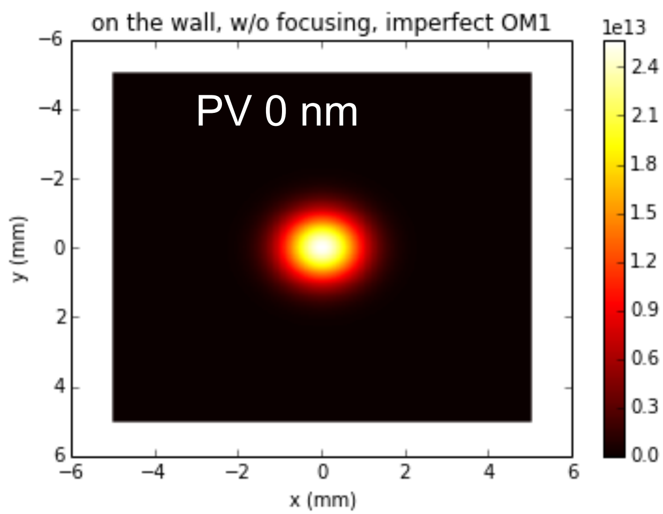
Liubov Samoylova, Maurizio Vannoni

SASE1 beamline, simulated with:

12.4 KeV (= wl 0.1 nm), distance 625 m,

grazing angle 2 millirad,

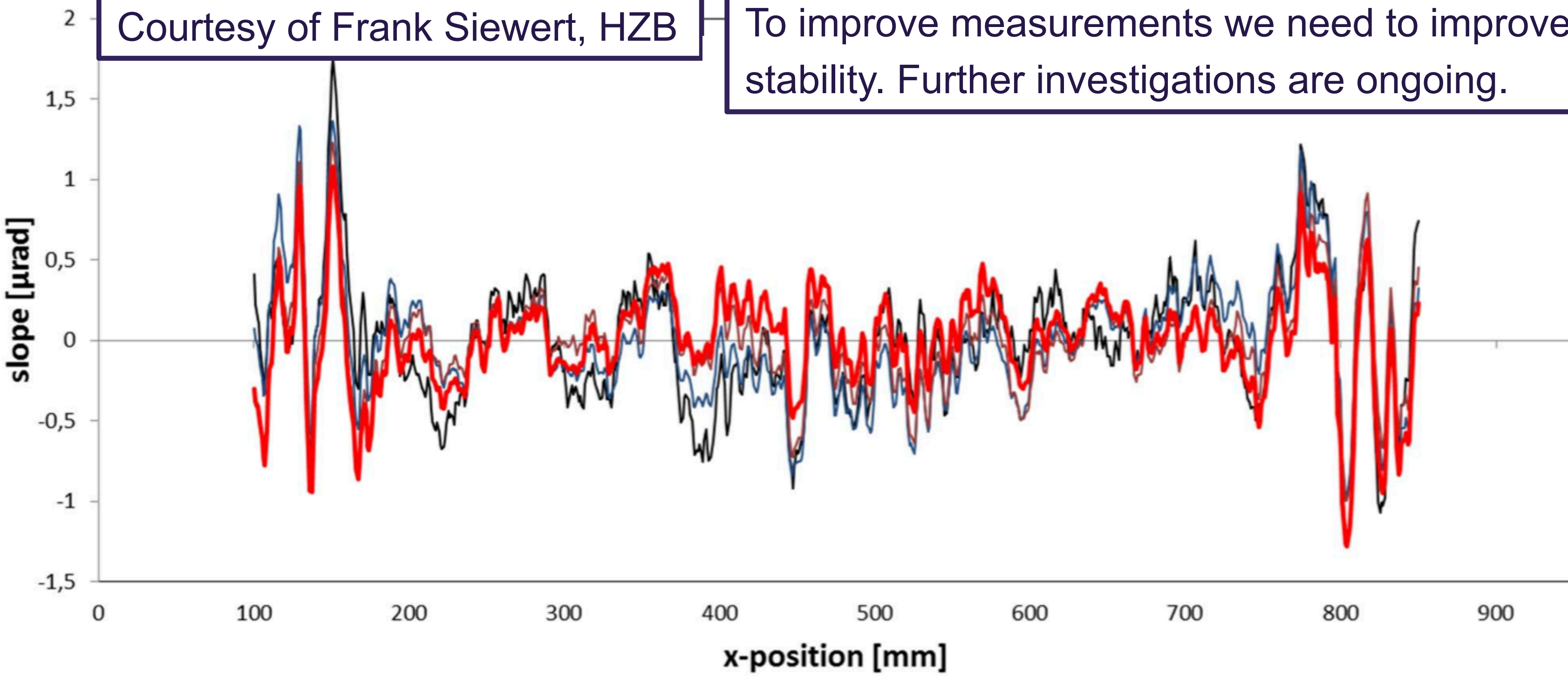
e-bunch charge 0.1 nC



Stability issues

Courtesy of Frank Siewert, HZB

To improve measurements we need to improve the stability. Further investigations are ongoing.

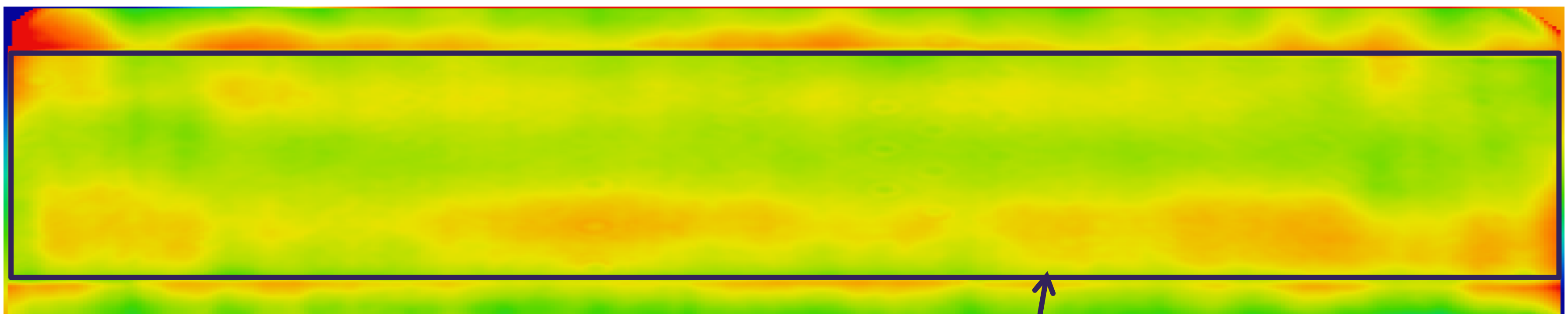


Residual slope: 0.31 µrad rms on 750 mm length

Radius of curvature: -650 km (convex)

Full surface measurements (THALES-SESO)

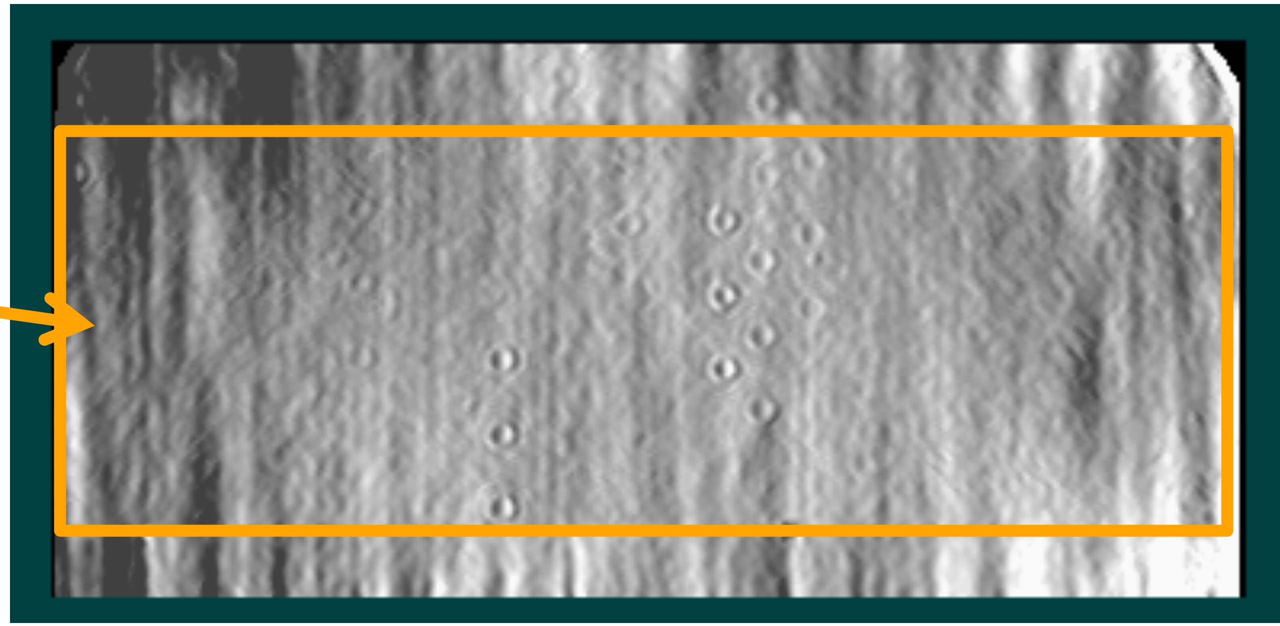
Height map



Ion Beam polished area

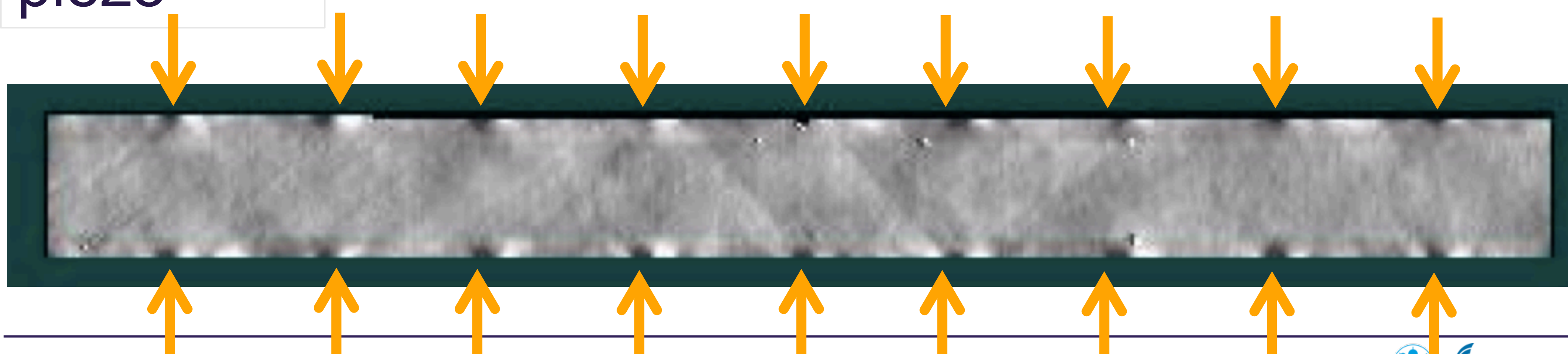
Full surface measurements (THALES-SESO)

Slope map



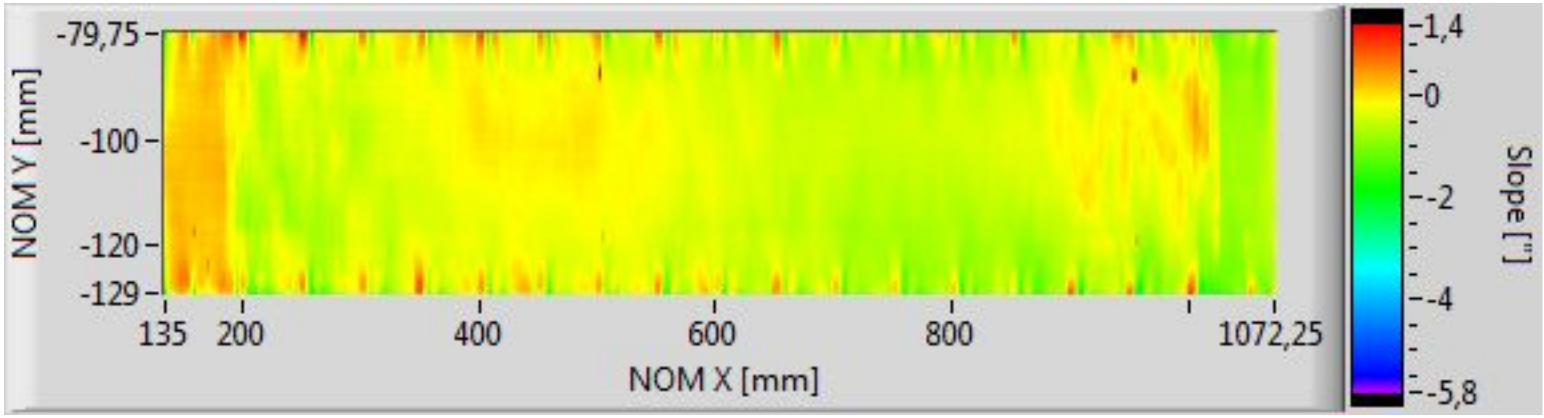
Ion Beam polished area

piezo



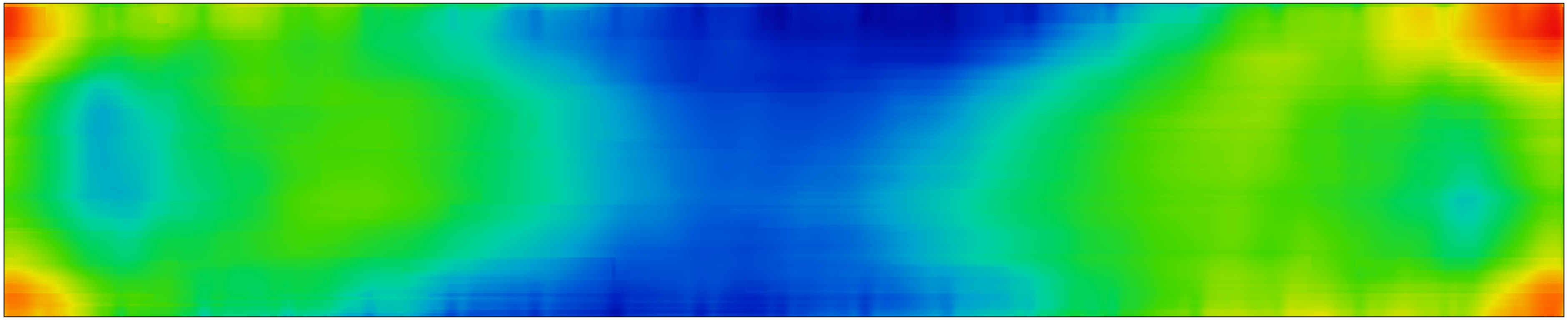
Full surface measurement (HZB)

Slope map

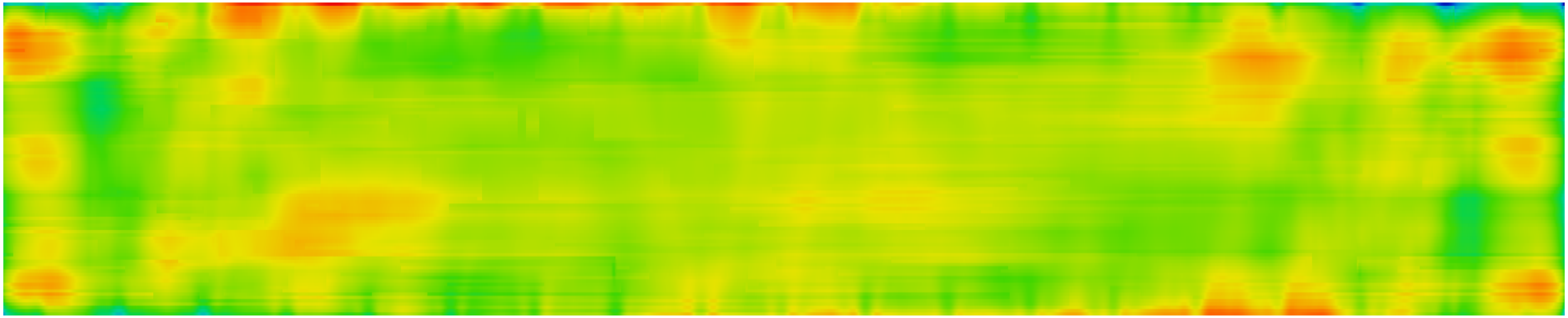


Full surface measurement (HZB)

Height map – face up



Height map – face up – polynomial subtracted



DESY HELMHOLTZ ASSOCIATION

Conclusions

- Present state:
  - The prototype is ok with specifications
  - The metrology is stretched to the limit but still reliable.
  - Combining height and slope measurements we retrieve additional information
- Further details to investigate
  - Piezo characterization, EEM polishing (JTEC), B4C coating, InGa cooling…

Acknowledgments

Special thanks to:

- Frank Siewert and HZB Helmholtz Zentrum Berlin

- Riccardo Signorato (formerly Bruker ASC, currently Strumenti scientifici CINEL)

- Luca Peverini (THALES-SESO)

- All the XFEL Optics and Beam Transport Group

WP-73 X-ray Optics & Beam Transport Group