Wavefront sensors at FLASH.

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FEL seminar
12.04.2016

Outline

- Intentions
- Wavefront sensor principle
- Different types of wavefront sensors available at FLASH
- Calibration measurement
- Alignment of a K-B optics system

Intentions

> 1. Beamline commissioning

- Alignment of focussing mirrors and K-B optics systems.
- Long-term observations of diagnostic tools and optical elements can be facilitated.

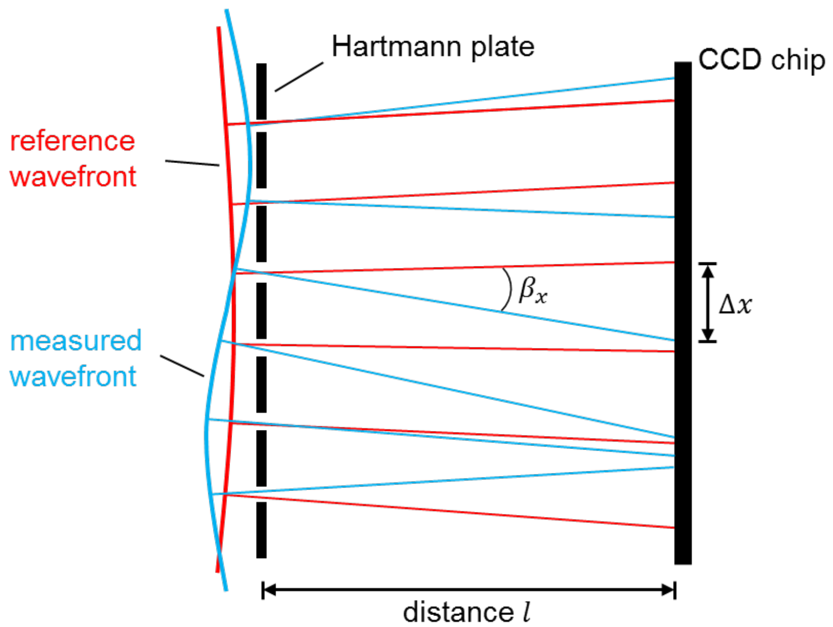
> 2. FEL characteristics

- The FEL source can be analysed in position, shape and size. The beam position and its stability can be documented.

> 3. Diagnostic for user experiments

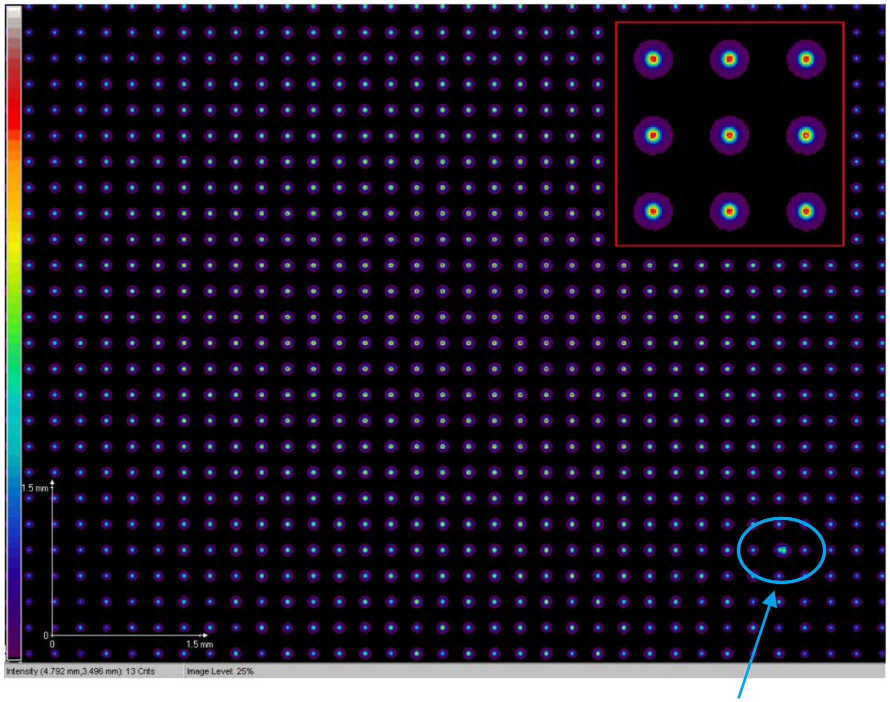
- Focus size and position can be determined online for single shots, if the main experiment is transparent for the FEL beam.

Wavefront sensor principle



The actual beam is compared to a reference wave (spherical wave).

Reference spot pattern



Alignment pinhole

Intensity and phase information of beam in single shot measurement:

- local intensity: amplitude of each spot
- local slope, wavefront phase: position of each spot

Large field of view wavefront sensor

Typically used in spectral region of 10 – 40 nm (up to 70nm)

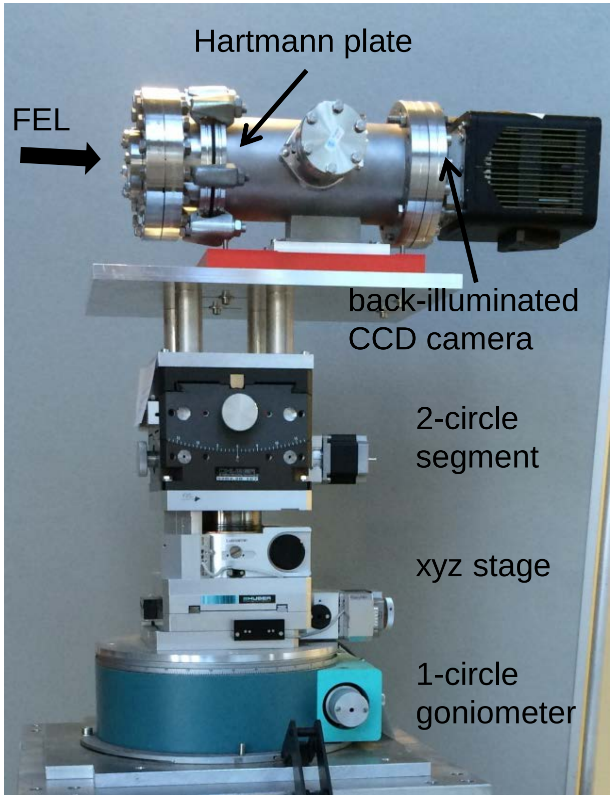
16-bit dynamic range back-illuminated CCD camera (PI-SX:1300) : 1340 x 1300 pixels with 20 µm x 20 µm pixel size → large field of view of 19.5 mm x 19.5 mm, 0.45 Hz operation

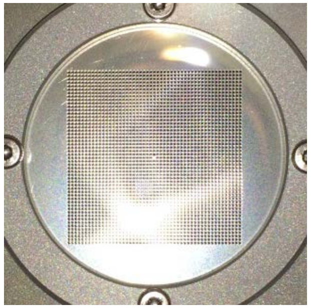
Hartmann plate: 80 µm Ni plate
51 x 51 quadratic holes
tilted by 25° to prevent interference of adjacent holes → increased spatial resolution, high dynamic range achieved

Distance Hartmann plate to CCD: 252 mm

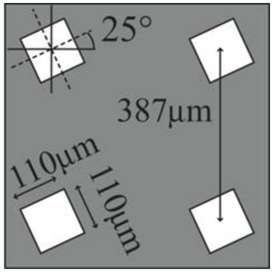
Wavefront repeatability for w_{rms}: specified to $\lambda_{13.4nm}/100$

Hardware was manufactured by Imagine Optic.
Software MrBeam 3.6.2 was written by LLG.





Hartmann plate

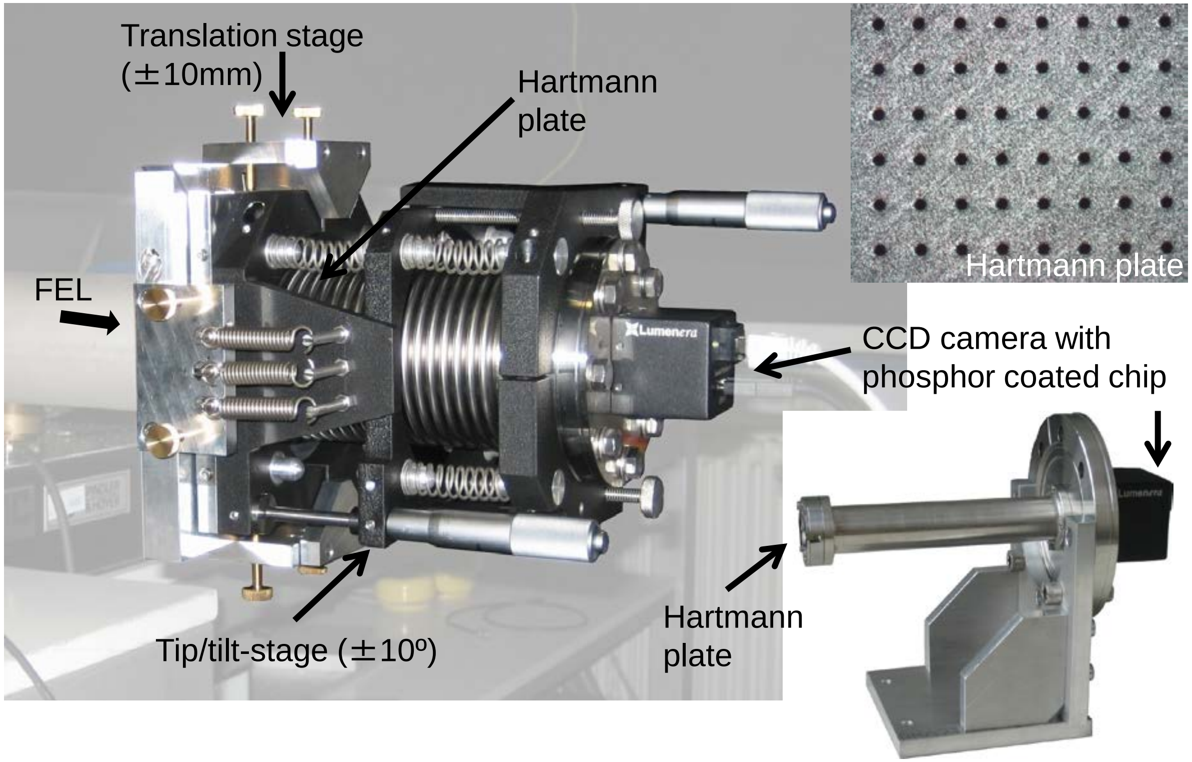


Very compact, self-supporting Hartmann sensor

Typical wavelength range of 4 - 35 nm

12-bit dynamic range CCD camera (Lumenera LM165M) :
1280 x 1024 pixels with 6.45 µm x 6.45 µm pixel size; chip coated with EUV-to-VIS quantum converter P43
field of view of 8.25 mm x 6.6 mm
10 Hz operation

Hartmann plate: 20 µm thick Ni foil with electroformed holes (75 µm diameter, 250 µm pitch) in a squared grid, no alignment pinhole



Distance Hartmann plate to CCD: 97.08 mm

Wavefront repeatability for w_{rms}: $\lambda_{13.5nm}/41$
→ limited by short distance between CCD and Hartmann plate and lower mechanical stability

Software MrBeam 3.5.0 was written by LLG.

Sensor is self-supporting.
Manual operating stage for x/y and tip/tilt movements.
Usable up to 80 nm due to small distance between CCD and Hartmann plate.

Build in collaboration with Laser-Laboratorium Göttingen e.V. (LLG)

B. Flöter et al., New J. of Phys. 12 (2010), 083015

Compact Hartmann sensor

Typical wavelength range of 4 - 38 nm

14-bit dynamic range CCD camera (Softhard SHT MR285MC): 1392 x 1040 pixels with 6.45 µm x 6.45 µm pixel size; chip coated with EUV-to-VIS quantum converter P43
field of view of 8.9 mm x 6.7 mm
10 Hz operation

Hartmann plate: 20 µm thick Ni foil with electroformed holes (75 µm diameter, 250 µm pitch) in a squared grid, alignment pinhole in the lower right corner

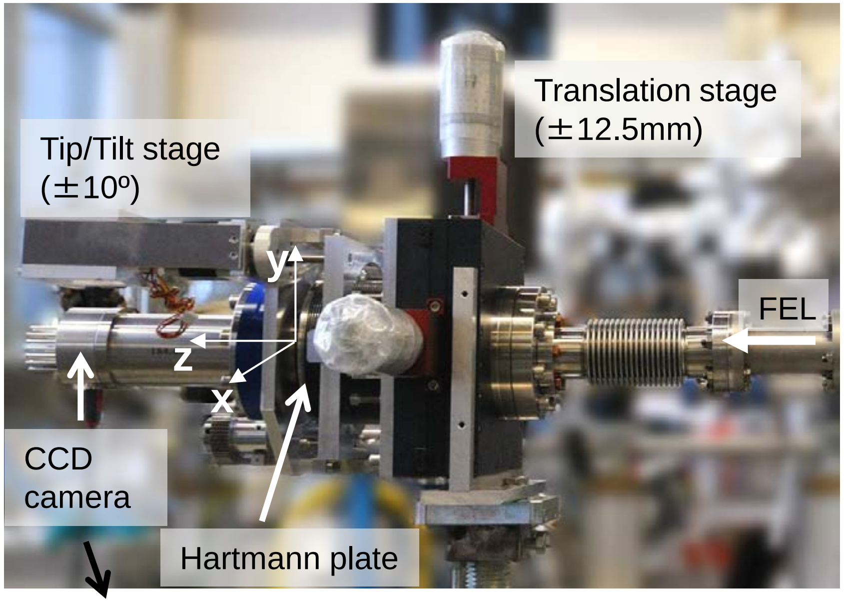
Distance Hartmann plate to CCD: 198.25 mm

Wavefront repeatability for w_{rms}: $\lambda_{13.5nm}/116$
→ due to longer distance between CCD and Hartmann plate

Higher mechanically stability and plane parallelism due to a rigid setup between CCD and Hartmann plate holder.

Manual operating stage for x/y and tip/tilt movements.

Software MrBeam 3.6.2 was written by LLG.



Hartmann plate

Build in collaboration with Laser-Laboratorium Göttingen e.V. (LLG)

B. Keitel et al., J. Synchrotron Rad. (2016). **23**, 43-49

Compact Hartmann sensor with larger field of view

Typical wavelength range of 4 - 38 nm

14-bit dynamic range CCD camera (XIMEA MR4021MU):
2048 x 2048 pixels with 7.4 µm x 7.4 µm pixel size
chip coated with EUV-to-VIS quantum converter P43
field of view of 15.2 mm x 15.2 mm
5 Hz operation

Hartmann plate: 10 µm thick Ni foil with electroformed holes (75 µm diameter, 250 µm pitch) in a squared grid, closed hole in the centre for alignment purpose

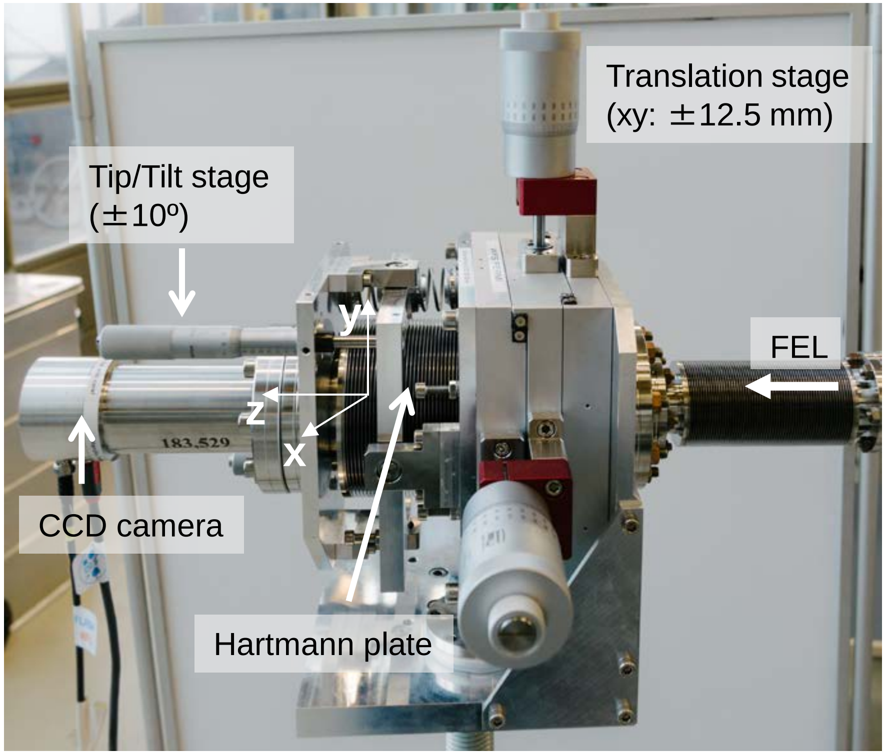
Distance Hartmann plate to CCD: 199.953 mm

Wavefront repeatability for w_{rms}: $\lambda_{13.5nm}/159$
→ due to longer distance between CCD and Hartmann plate

High mechanically stability and plane parallelism due to a rigid setup between CCD and Hartmann plate holder.
Plate diameter increased by a factor of 1.5.

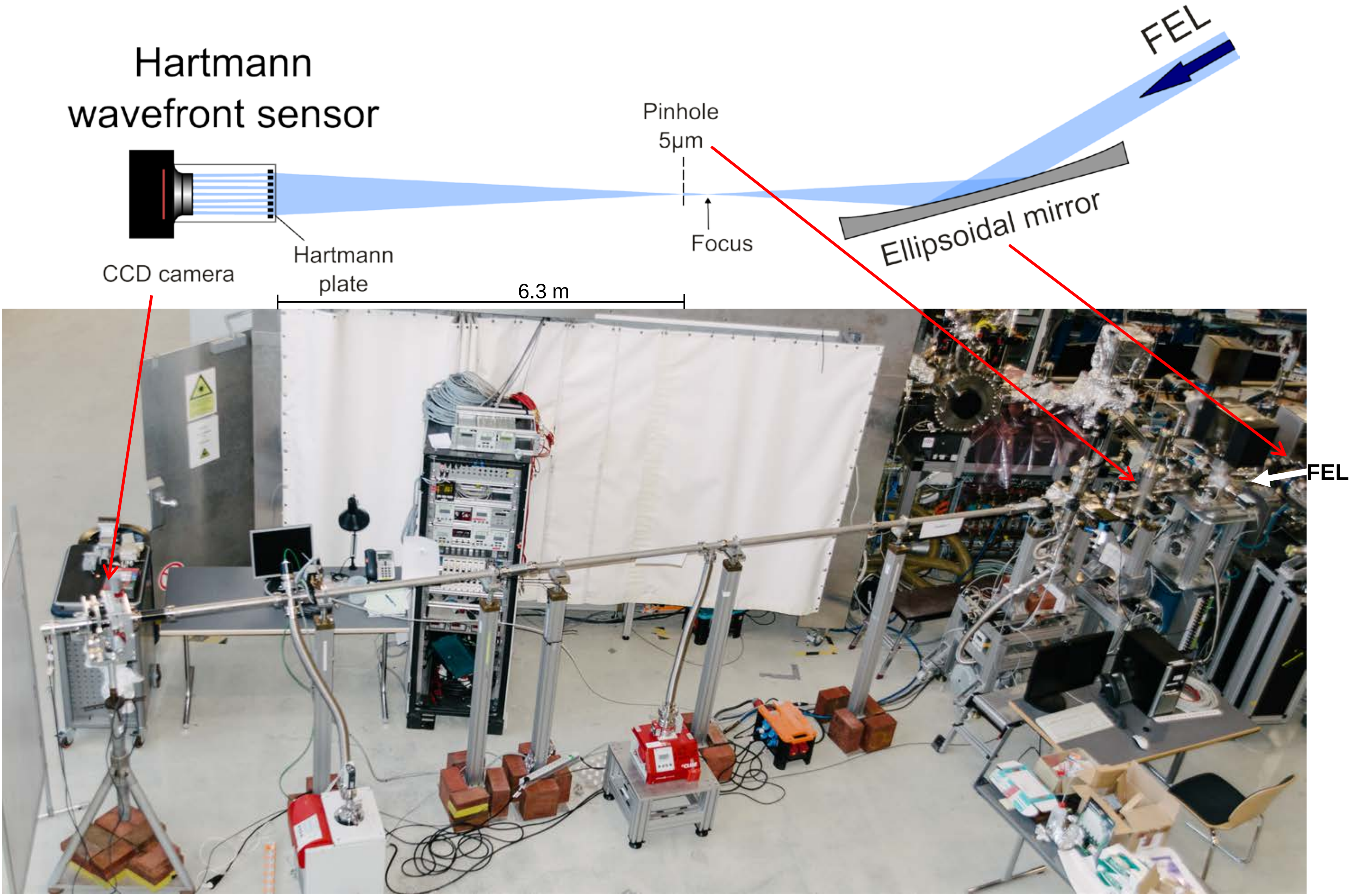
Manual operating stage for x/y and tip/tilt movements.

Software MrBeam 3.6.3 was written by LLG.



Build in collaboration with Laser-Laboratorium Göttingen e.V. (LLG)

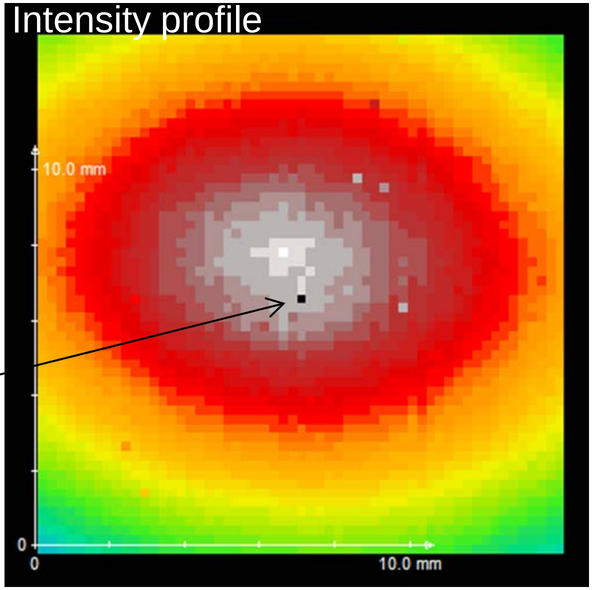
Setup for calibration measurements at BL2

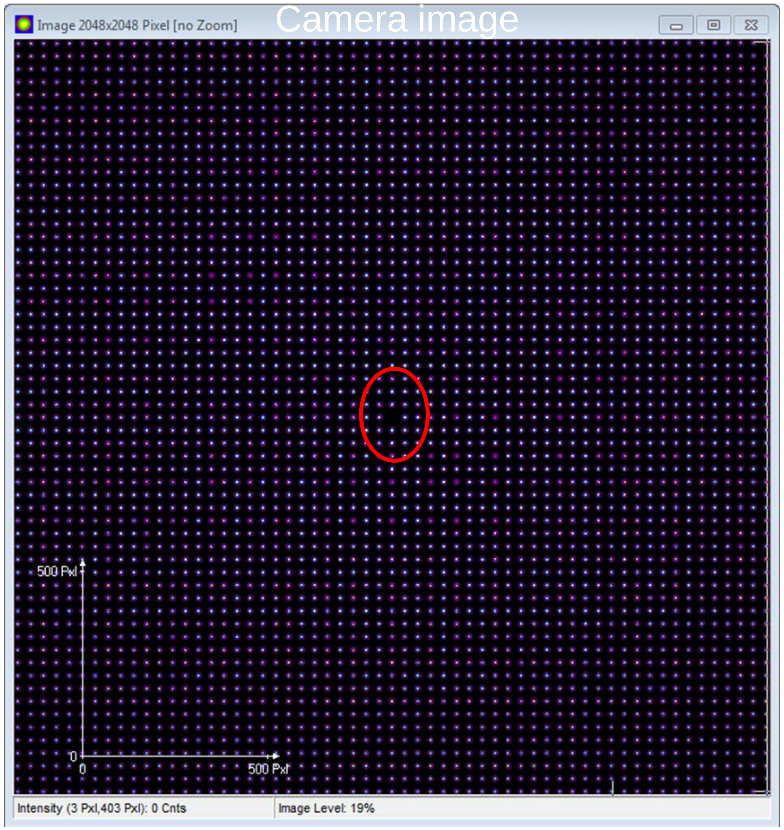


Calibration measurements at BL2

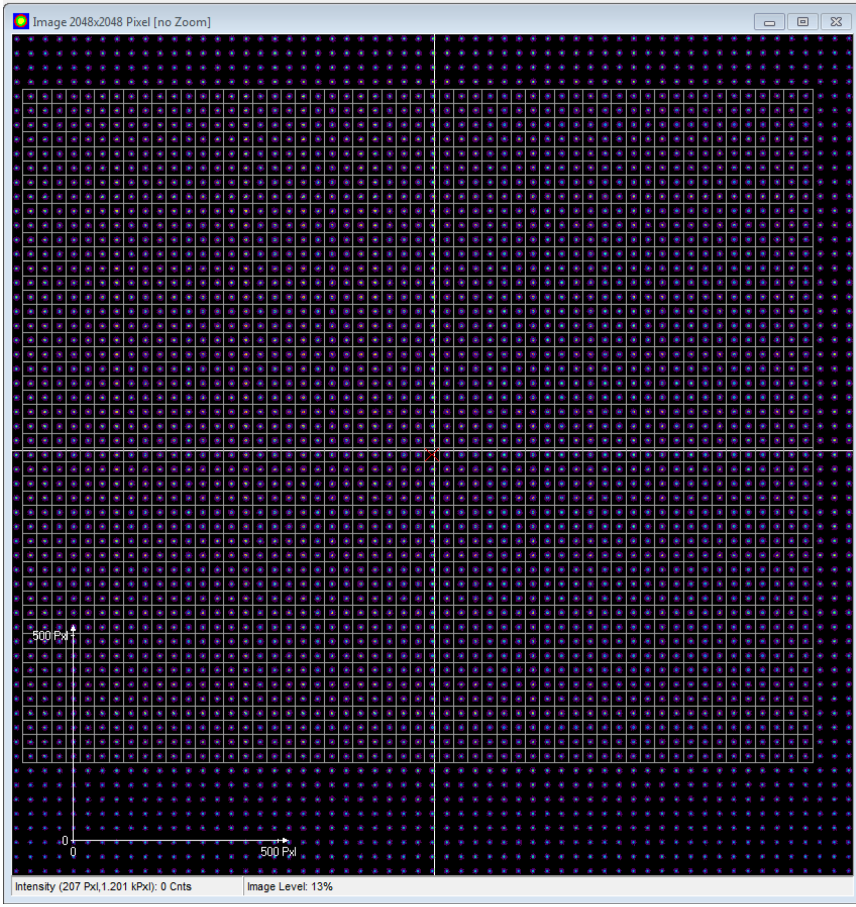
- Wavelength 13.5 nm
- Pulse train of 30 bunches
- Single pulse energy ~ 140 µJ
- No attenuation of the beam by filter foils or the gas attenuator
- Chopper with 5 Hz
- 5 s exposure time of the camera
- 750 pulses averaged to improve signal-to-noise ratio

Closed hole for alignment purpose

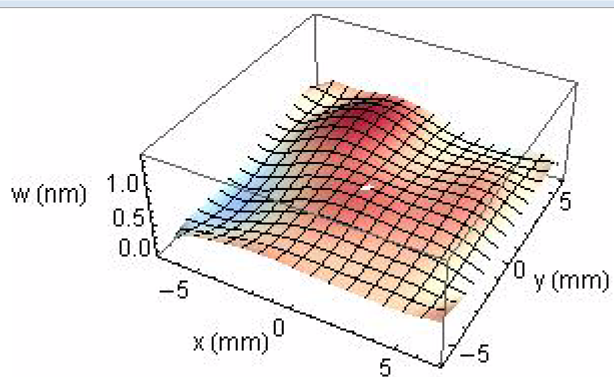




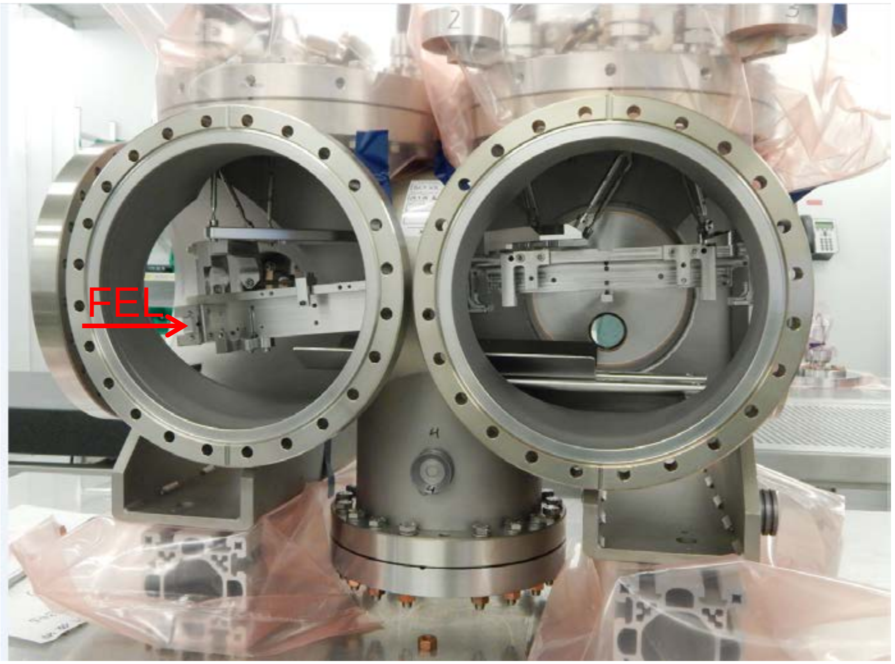
Measuring a sequence with the new reference file

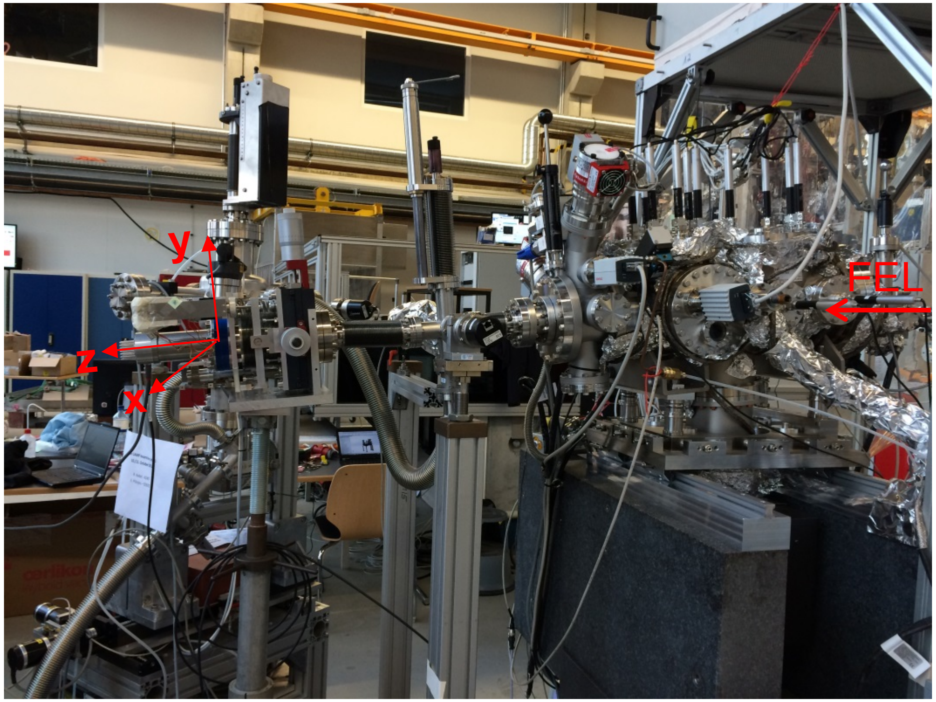


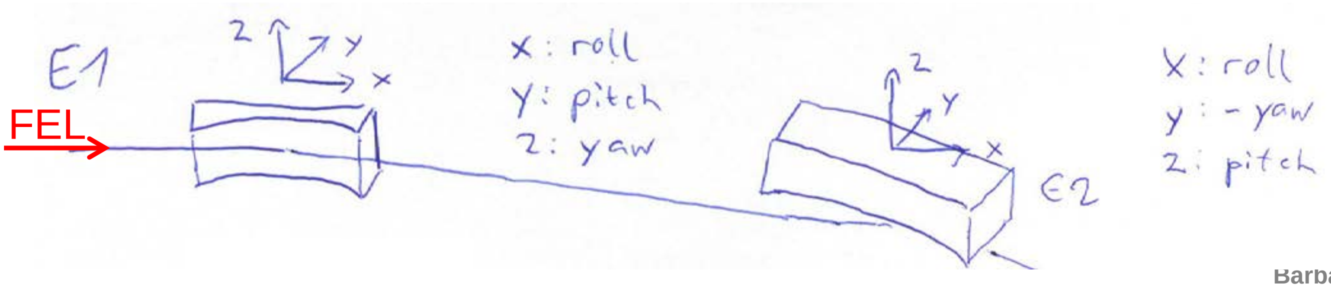
	Sequence11_hotpixel Grid 55 x 47 mean of 50 camera images (450 pulses)
Evaluation Radius (mm)	8.867
PV Irregularity (nm)	0.575 ± 0.121
rms Deformation (nm)	0.088 ± 0.014
Repeatibility of WF rms	λ_{14nm} / 159
Beam width X (mm) Beam width Y (mm)	15.311 ± 0.003 (4σ) 9.014 ± 0.002 (fwhm) 12.901 ± 0.004 (4σ) 7.595 ± 0.002 (fwhm)
Waist Position X (mm) Waist Position Y (mm)	-6344.89 ± 0.09 -6344.83 ± 0.26
Waist Diameter X (µm) Waist Diameter Y (µm)	2.08 ± 0.12 (4σ) 1.22 ± 0.07 (fwhm) 2.57 ± 0.09 (4σ) 1.51 ± 0.05 (fwhm)
Divergence X (mrad) Divergence Y (mrad)	2.41310 ± 0.00047 2.03331 ± 0.00065



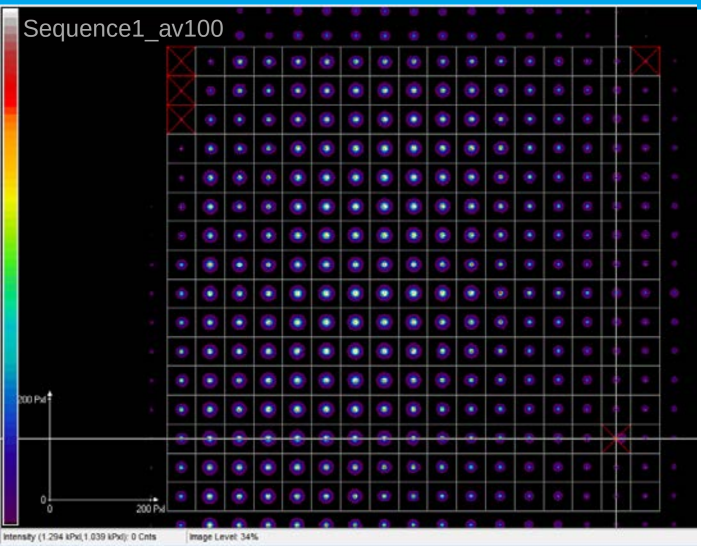
Alignment of the K-B optics system at BL1 using the compact wavefront sensor

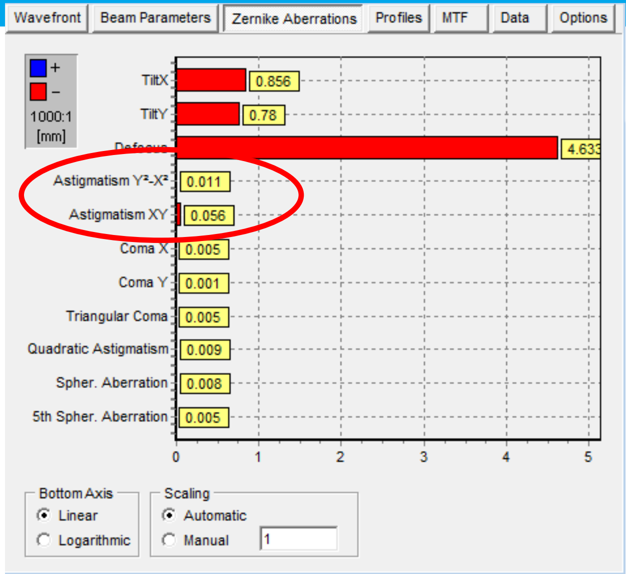






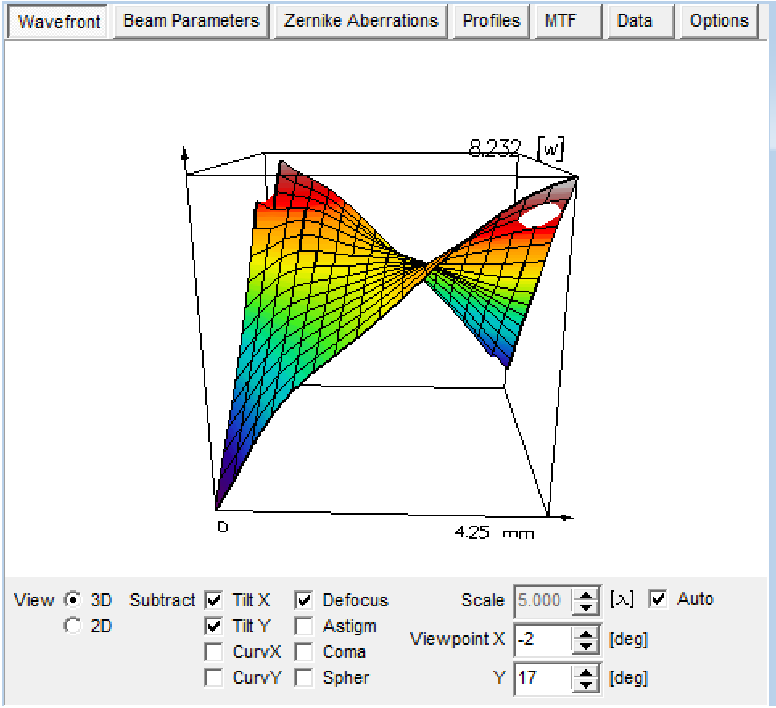
Start of K-B optics system alignment at BL1





λ = 13.5 nm, 0.36 nC
single bunch with 64 µJ
both 5 mm apertures in tunnel
Nb 384.8 nm (filter wheel 1)
Al 101.2 nm (filter wheel 2)

Average of 100 single bunches on CCD chip.

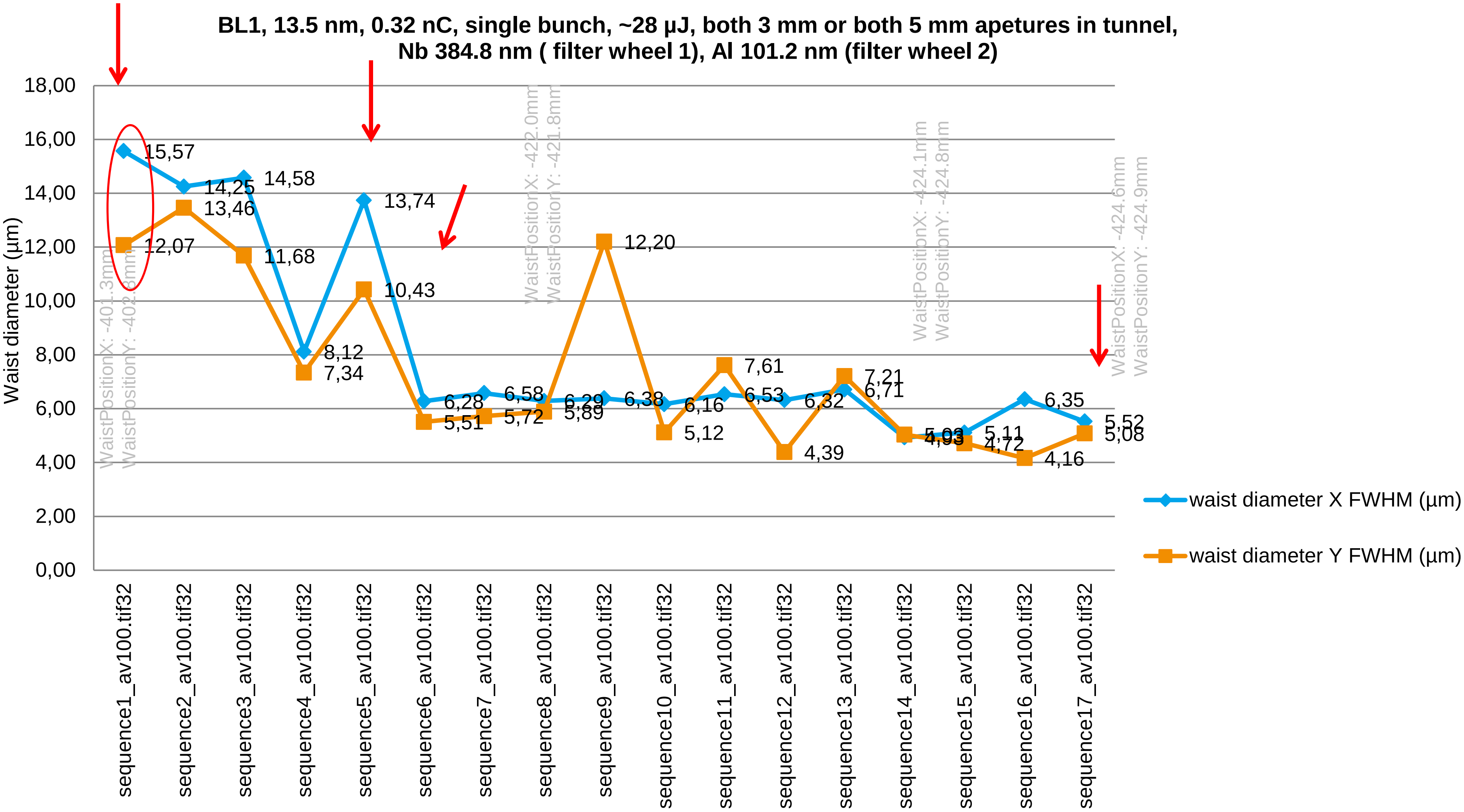


Wavefront | Beam Parameters | Zernike Aberrations | Profiles | MTF | Data | Options

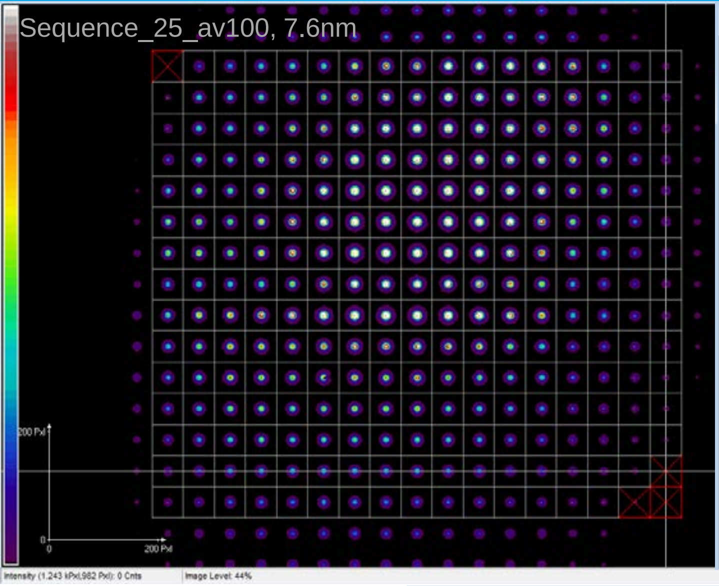
rms Deformation	[mm]	1.523068E-5	RayleighLengthX	[mm]	3.1047
pv Irregularity	[mm]	0.0001087206	RayleighLengthY	[mm]	1.9731
Defocus	[mm]	402.3443	Slope rms	[mrad]	3.3555
General Astigm.		0.9877977	Slope max	[mrad]	1.0000
Strehl		0.0000	Beam Ellipticity		0.76
M² ²		13.4901			

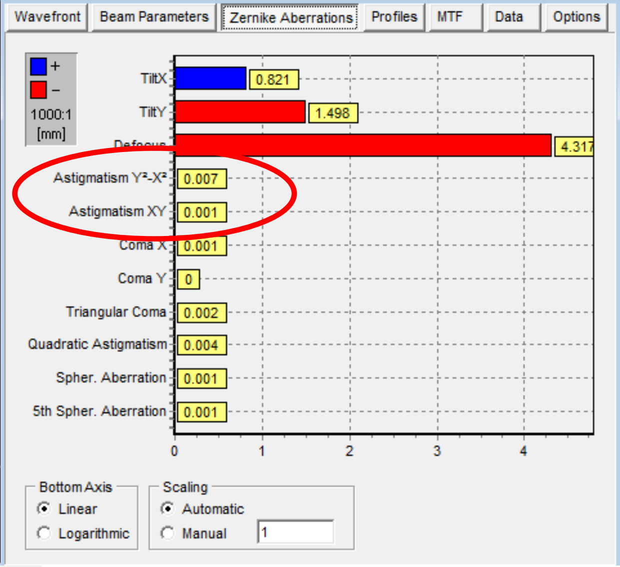
Angle / MainAxis		0°	45°	-21.54°
M² X		12.6363	4.9955	11.6584
M² Y		11.9518	5.3604	11.2341
DivergenceX	[mrad]	8.5177	8.5048	8.0671
DivergenceY	[mrad]	10.3910	10.4016	10.7446
BeamWidthX	[mm]	3.4178	3.4454	3.2564
BeamWidthY	[mm]	4.1858	4.1631	4.3126
WaistPositionX	[mm]	-401.2515	-405.1158	-403.6465
WaistPositionY	[mm]	-402.8216	-400.2350	-401.3699
WaistDifference	[RL]	0.6184	-4.6170124	-0.9239
WaistDiameterX	[mm]	0.0264447	0.0104701	0.0257607
WaistDiameterY	[mm]	0.0205028	0.0091861	0.0186375

Alignment of K-B optics system



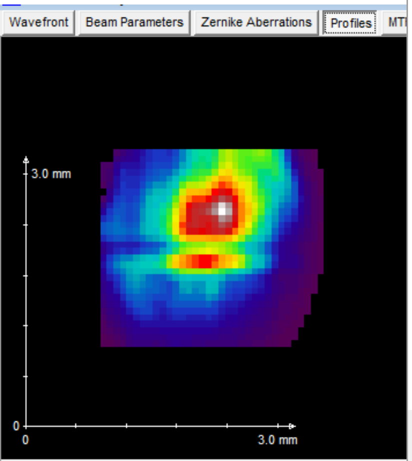
End of K-B optics system alignment at BL1

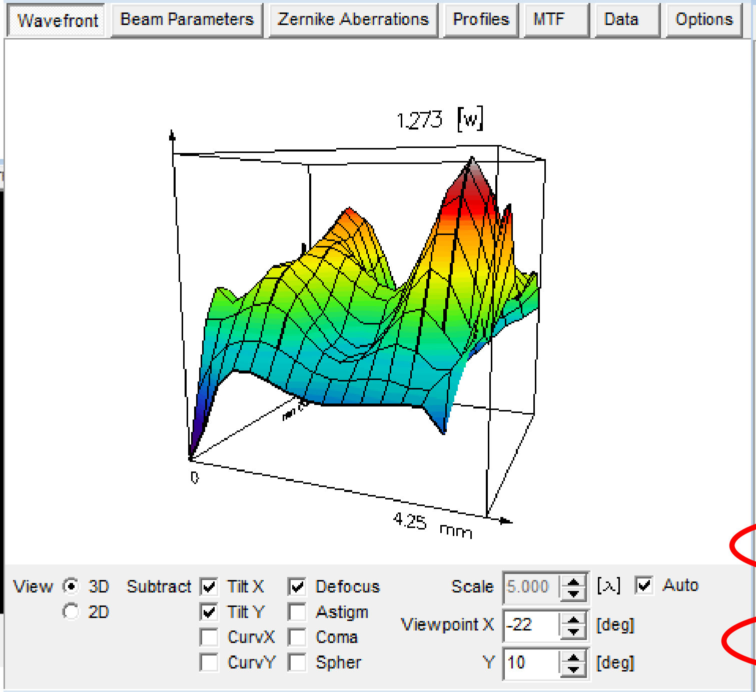




λ = 7.6 nm, 0.34 nC,
single bunch with 50 µJ
both 3 mm apertures in tunnel
Nb 197 nm (filter wheel 1)
Al 198.3 nm (filter wheel 2)

Average of 100 single bunches on CCD chip.



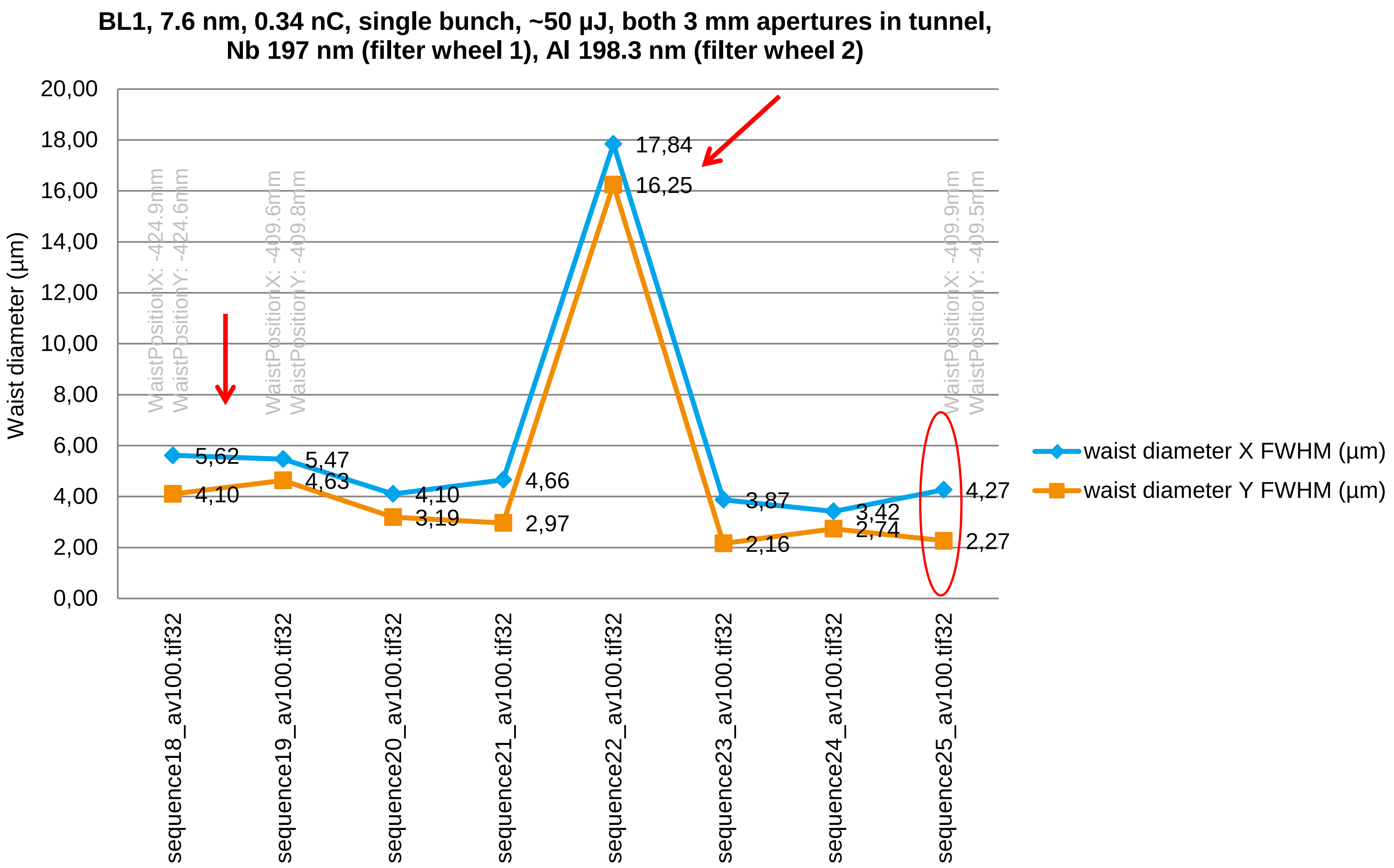


Wavefront | Beam Parameters | Zernike Aberrations | Profiles | MTF | Data | Options

rms Deformation [mm]	1.793575E-6		RayleighLengthX [mm]	0.8460
pv Irregularity [mm]	8.279986E-6		RayleighLengthY [mm]	0.4533
Defocus [mm]	409.6916		Slope rms [mrad]	3.0171
General Astigm.	4.309774		Slope max [mrad]	1.0000
Strehl	0.1369		Beam Ellipticity	0.80
M² ²	18.3516			

Angle / MainAxis	0°	45°	43.67°
M² X	6.1041	4.8939	5.1474
M² Y	3.2117	5.0664	4.8504
DivergenceX [mrad]	8.5730	7.5415	9.4236
DivergenceY [mrad]	8.4953	9.4229	7.5406
BeamWidthX [mm]	3.5141	3.0904	3.8603
BeamWidthY [mm]	3.4785	3.8599	3.0899
WaistPositionX [mm]	-409.9053	-409.7767	-409.6403
WaistPositionY [mm]	-409.4675	-409.6319	-409.7635
WaistDifference [RL]	-0.6740	-0.1986658	0.1690
WaistDiameterX [mm]	0.0072526	0.0066098	0.0055638
WaistDiameterY [mm]	0.0038509	0.0054767	0.0065520

Alignment of K-B optics system



Results

- Only part of the beam could be used for evaluation:
  - In vertical direction the beam exceeds the CCD.
  - The boundary area of the spot could not used for evaluation due to high divergence of the beam.
- Beam parameter calculation only possible for full coherent beams.
- Focus size expected to be slightly bigger by an unknown factor.

Conclusions and outlook

> The compact Hartmann sensor with a larger field of view will be a valuable diagnostic tool during the beamline commissioning at FLASH and FLASH2.

> Online diagnostic (wavefront, aberration, focus position,…) for single pulses is possible with 5 Hz.

Many thanks to …

T. Mey, M. Lübbecke, J.-O. Dette, B. Schäfer, *K. Mann*
Laser-Laboratorium Göttingen e.V.

E. Plönjes, M. Kuhlmann, S. Kreis, M. Brachmanski, K. Tiedtke
FS-FL

the whole FS-FL and FLASH team