FEL Wave-front Measurements in the Soft X-ray Region at FLASH

Elke Plönjes, Pavle Juranic, Barbara Keitel, Marion Kuhlmann, Kai Tiedtke
HASYLAB at DESY

Guillaume Dovillaire
Imagine Optic, France

Bernhard Flöter, Klaus Mann, Bernd Schäfer
Laser Laboratorium Göttingen

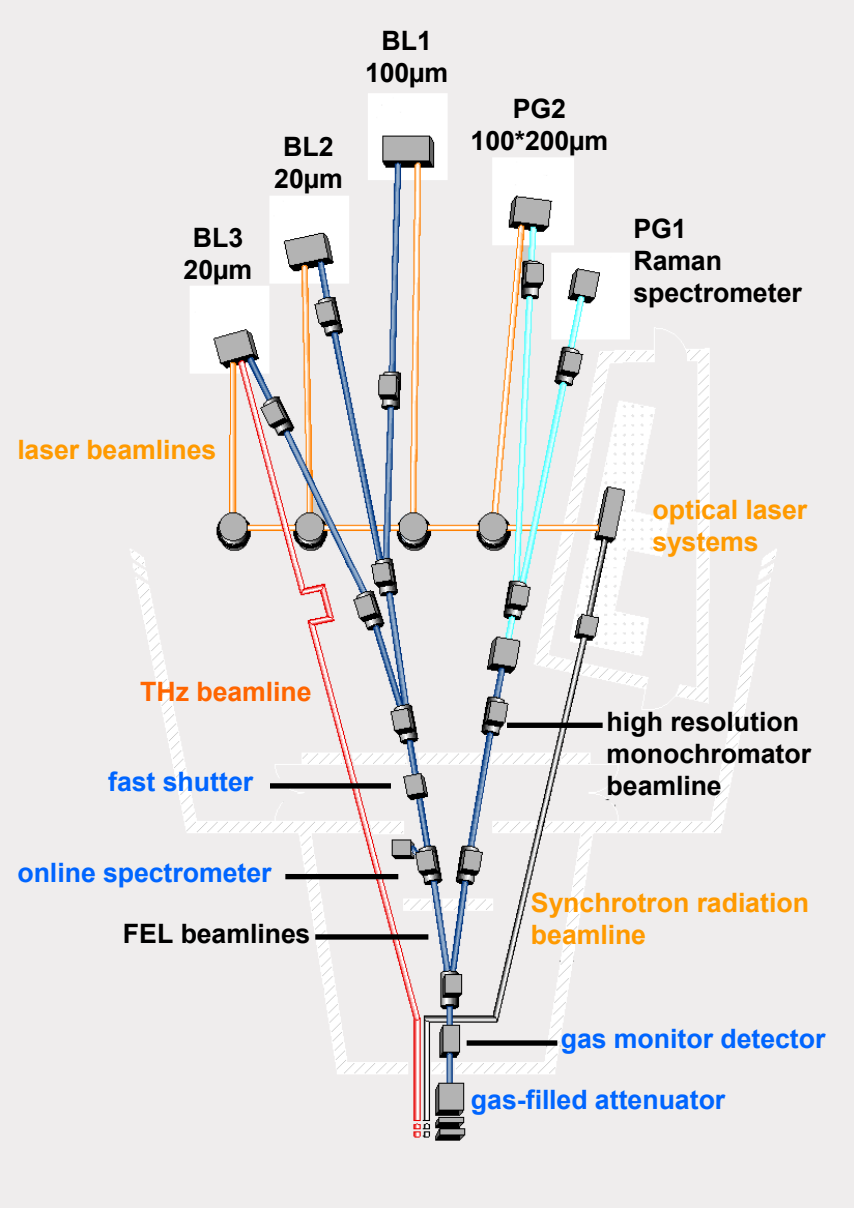
Intention

1. **Beamline commissioning**
   A first implementation as well as long-term observations of diagnostic tools and optics can be facilitated.
   - **Mirror alignment of BL1 and BL2**
   - **Effects of filters and gas attentuator on FEL wavefront**

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.

Experimental hall



Flash conditions

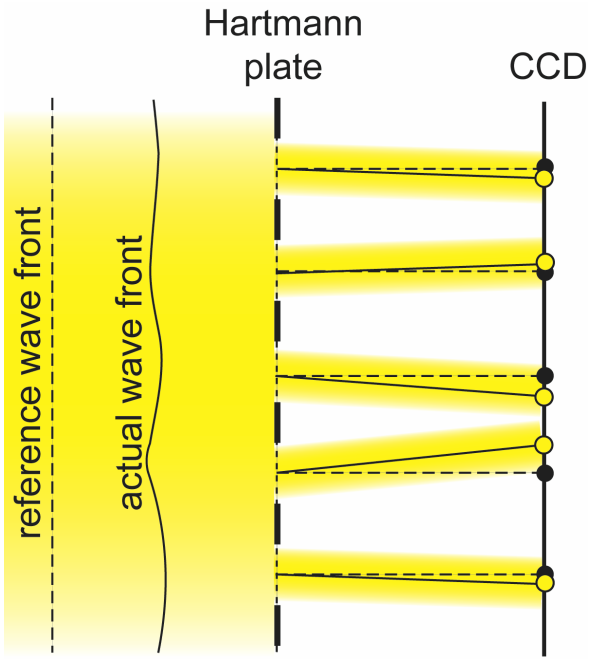
VUV and soft x-ray regime
- 50 nm -6.5 nm
- spectral shot to shot fluctuations
- higher harmonics up to the 7th
- particle-free UHV

High intensity levels
- ~10 - 50 µJ
- intensity fluctuations of two orders of magnitude

Pulse durations of 10 - 50 fs

Variable time structures
- 2 or 5Hz bunch train repetition
- 1- 300 bunches in train
- 1-800 bunches with 10Hz in the near future

The Hartmann sensor principle



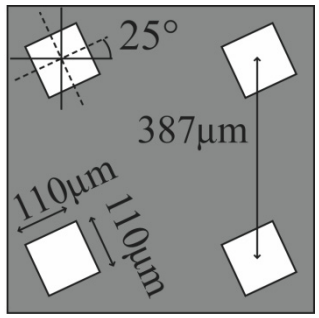
The actual beam is compared to a perfect spherical wave

Wave front sensor

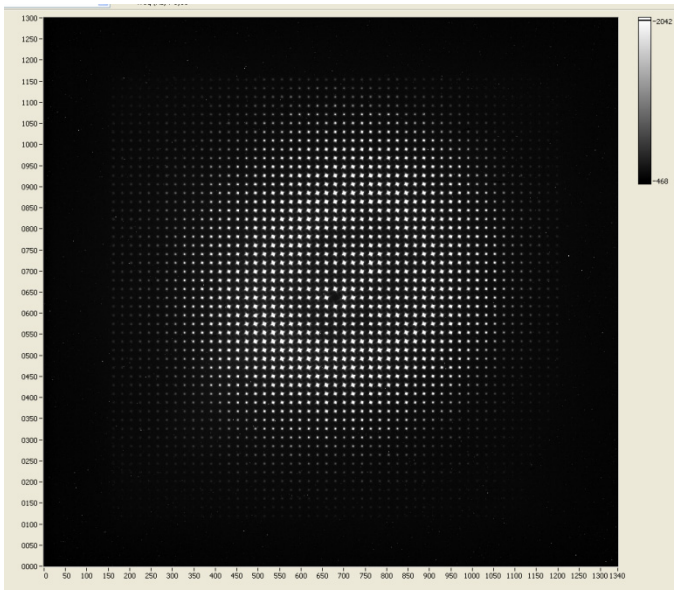
soft- and hardware by Imagine Optic

CCD: field of view = 19.5 x 19.5 mm
1340 x 1300 pixels

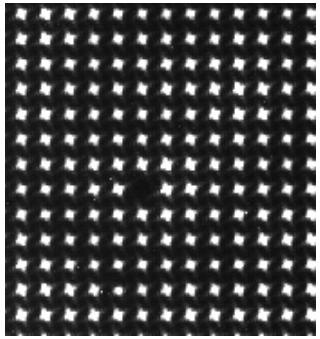
Hartmann plate: 51 x 51 quadratic holes tilted by 25° to prevent interference of adjacent holes



camera image



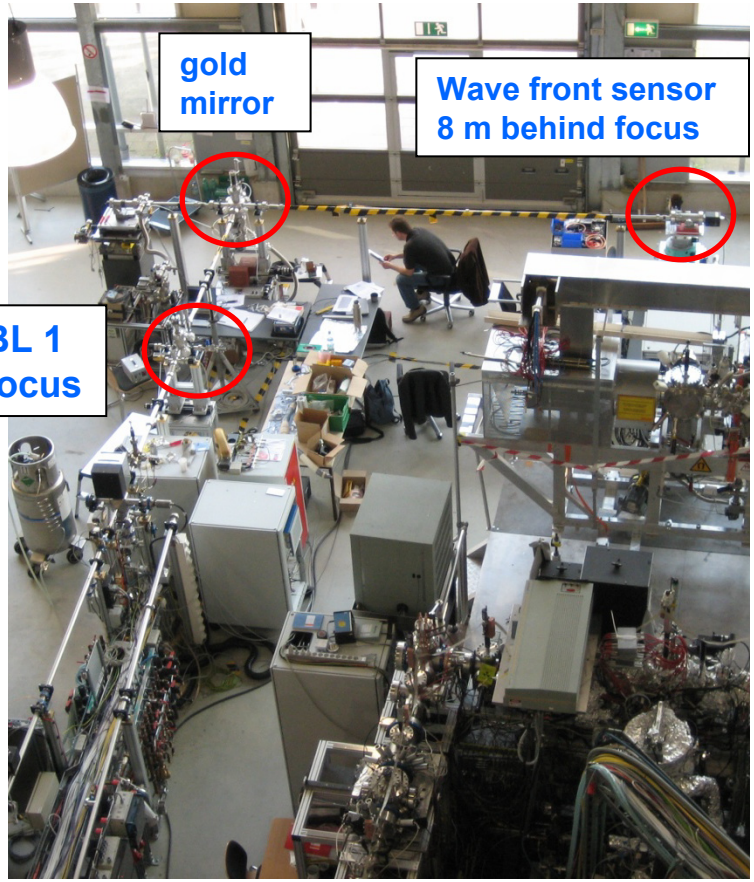
camera image zoom

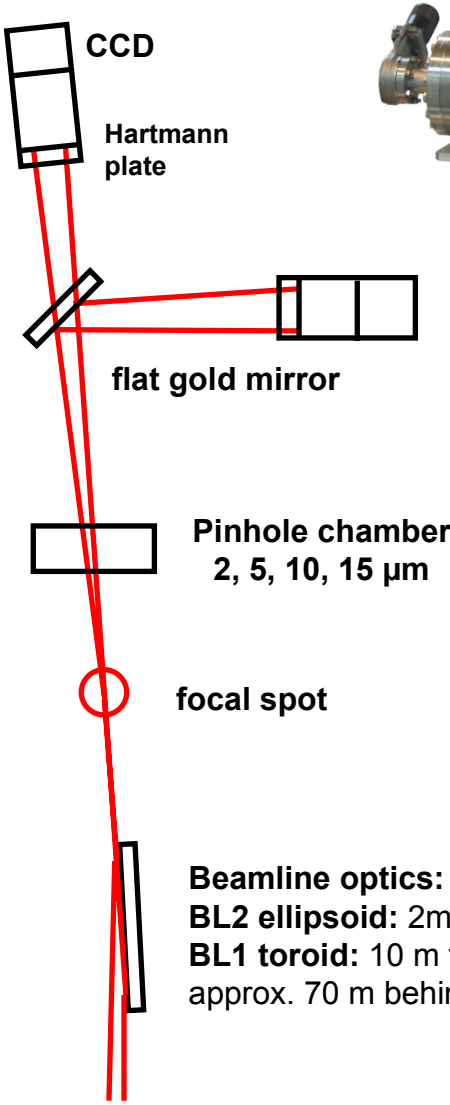


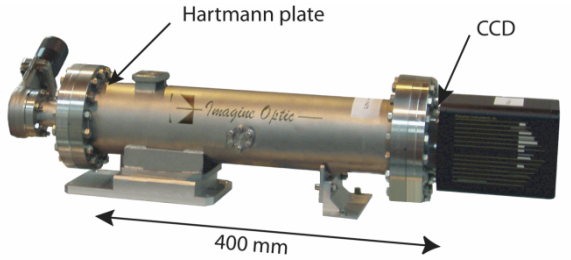
Courtesy Pascal Mercère, SOLEIL

Wavefront sensor setup at FLASH beamline

Beamline BL 1



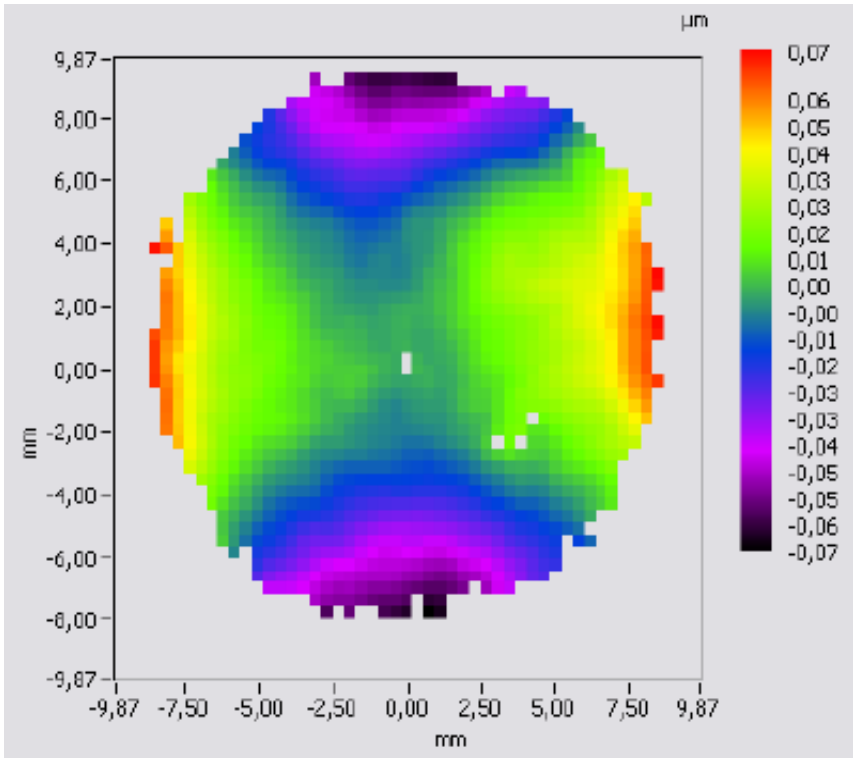


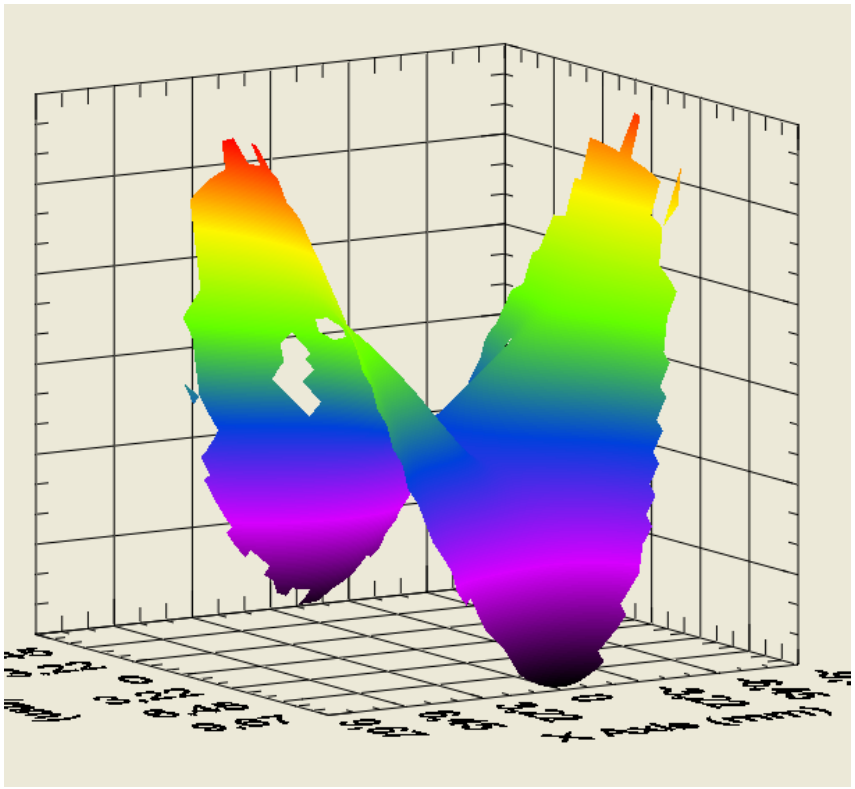


Beamline optics:
BL2 ellipsoid: 2m focal length
BL1 toroid: 10 m focal length
approx. 70 m behind FEL source

Typical misaligned wavefront

Beamline BL2 before alignment





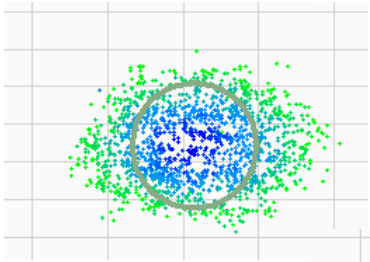
Rotation: 0 Yaw: 0

PV: 110 nm rms: 22 nm@ 27 nm
→ λ/1

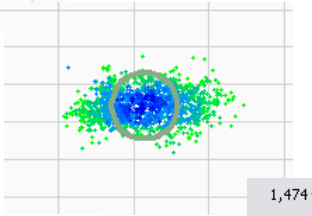
Radius (2σ) : 42.3µm

Ray tracing modeling for BL2:
FWHM: 20 µm → radius (2σ): 16µm

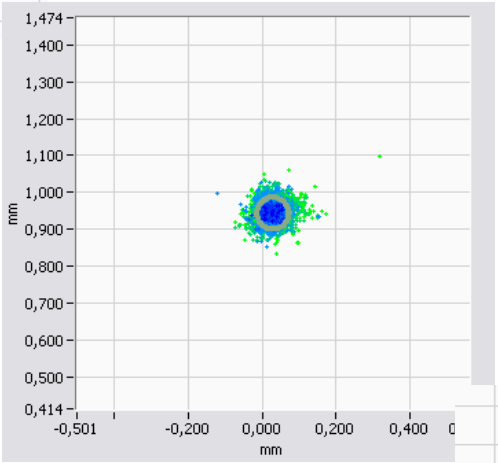
Before adjusting ellipsoidal mirror of BL2



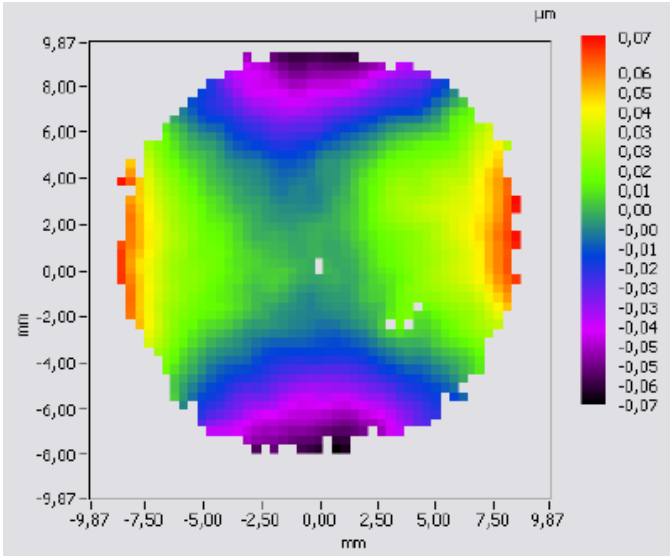
defocus 100mm
radius 164.9µm



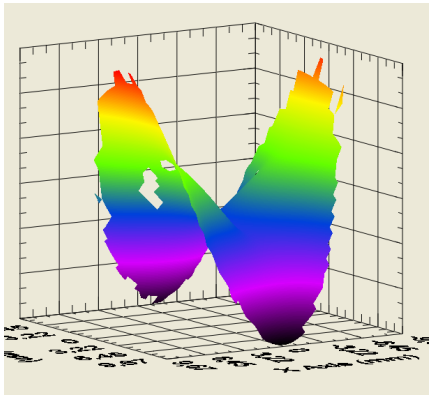
defocus 50mm
radius 87.8µm

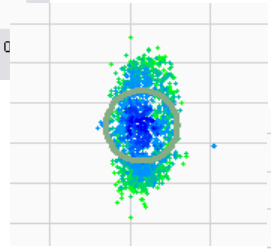


defocus 0mm
radius 42.3µm

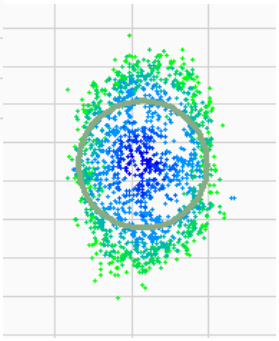


Rotation: 0 Yaw: 0
PV: 110nm rms: 22nm @ 27 nm
→ λ/1



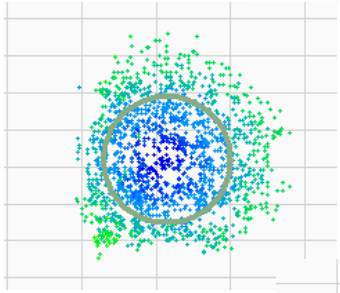


defocus -50mm
radius 88.9µm

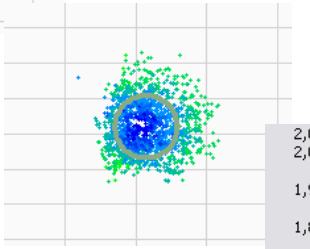


defocus -100mm
radius 166.0µm

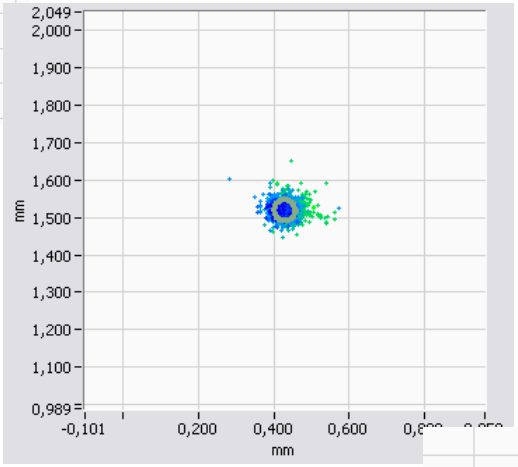
During adjustment of BL2



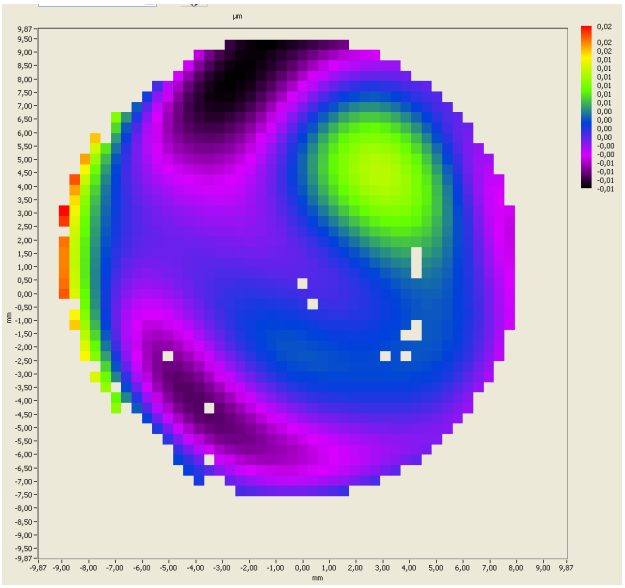
defocus 100mm
radius 170.7µm



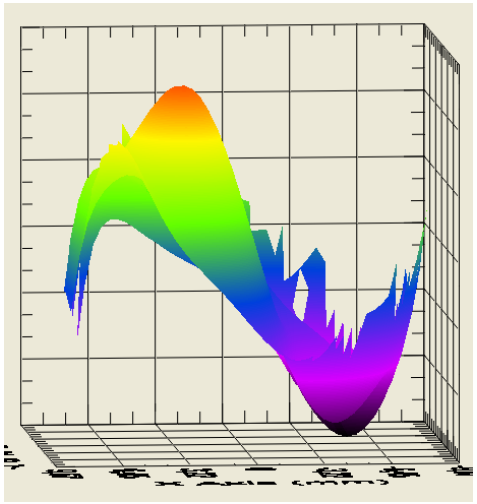
defocus 50mm
radius 88.1µm

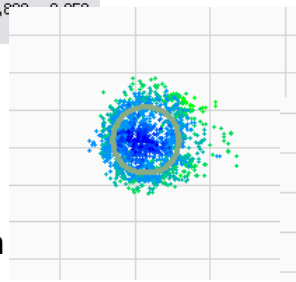


defocus 0mm
radius 27.7µm

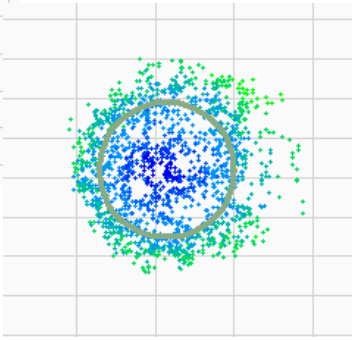


Rotation: 45000 (~1 mrad)
Yaw: 0
PV: 30nm rms: 5nm @ 27 nm
→ λ/5



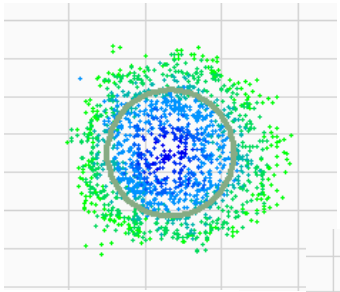


defocus -50mm
radius 88.3µm

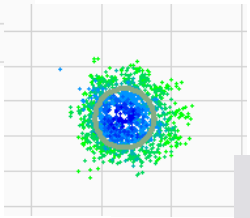


defocus -100mm
radius 170.9µm

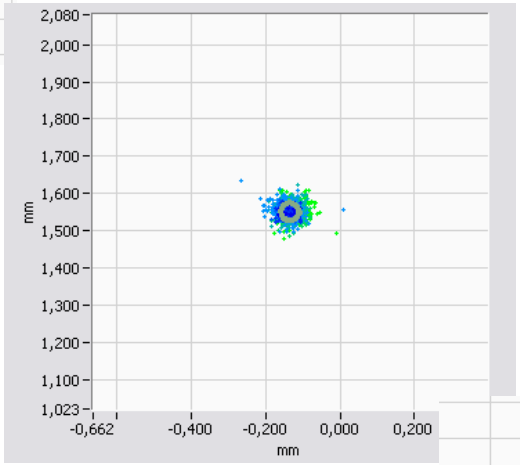
After adjustment of BL2



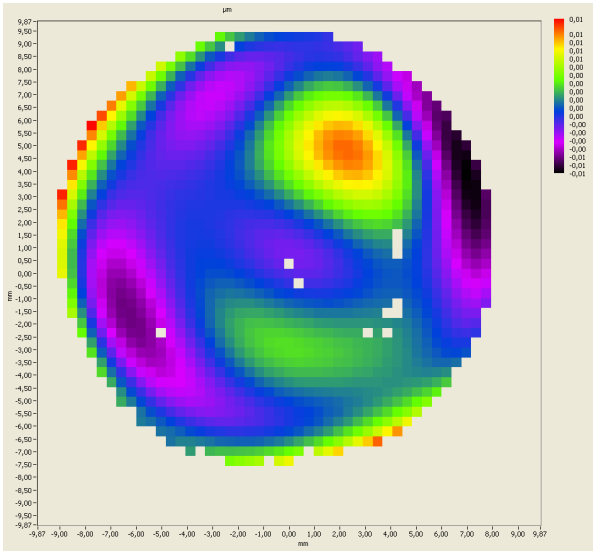
defocus 100mm
radius 165µm



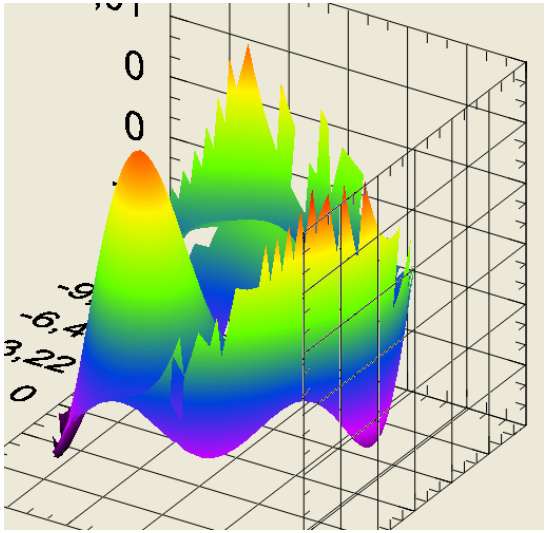
defocus 50mm
radius 84.1µm

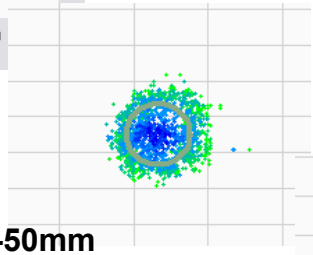


defocus 0mm
radius 24.1µm

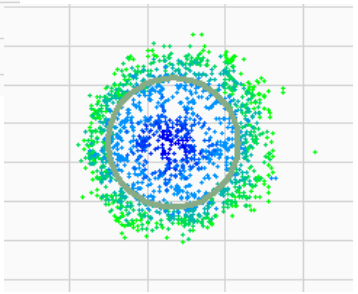


Rotation: 45000 Yaw: -0.01
PV: 18 nm rms: 3 nm @ 27 nm
→ λ/9



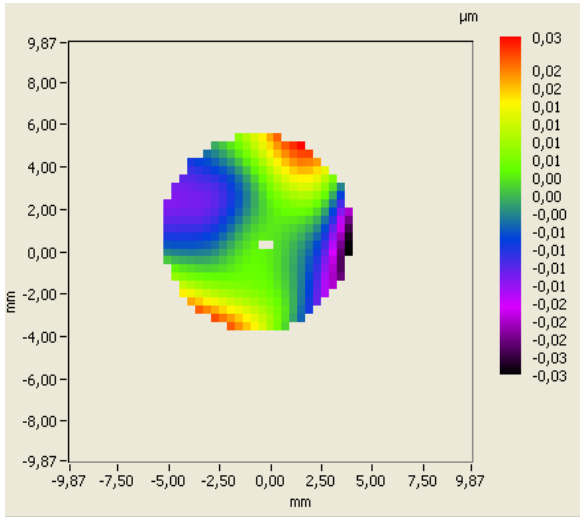


defocus -50mm
radius 85.2µm



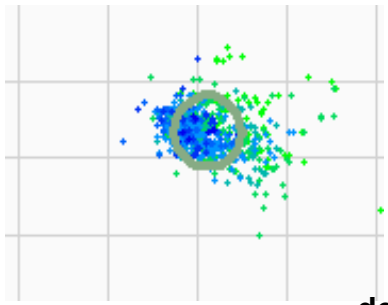
defocus -100mm
radius 166µm

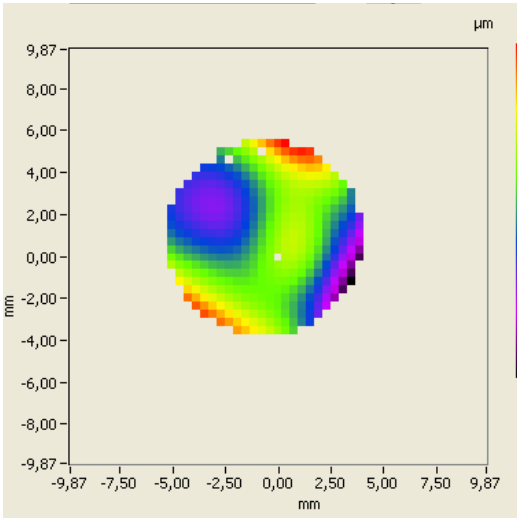
Alignment of BL 1



Horizontal: 0
Rotation: 0 Yaw: 0
PV: 56 nm, rms: 10 nm @ 27 nm
→ λ/3

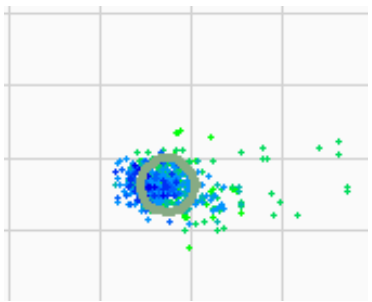
radius: 86.1µm
file 08042501.himg

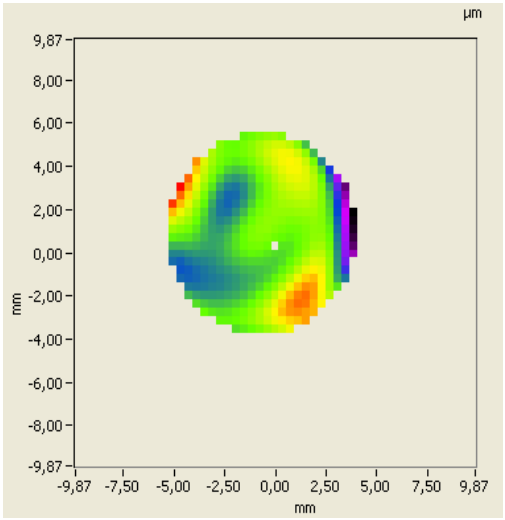




Horizontal: -1 mm
Rotation: 21000, Yaw: 0
PV: 39 nm, rms: 7 nm @ 27 nm
→ λ/4

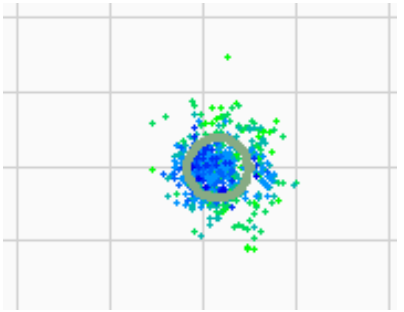
radius: 69.6µm
file 08042520.has





Horizontal: -1 mm
Rotation: 27000, Yaw: - 0.3
PV: 19 nm, rms: 3 nm @ 27 nm
→ λ/9

radius: 68.9µm
design value: 80µm
file 08042601.himg

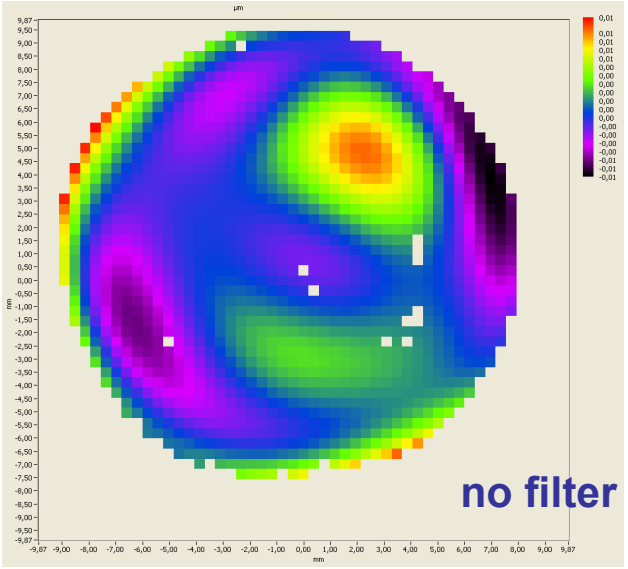


defocus -1 m

Filter and gas attenuator performance

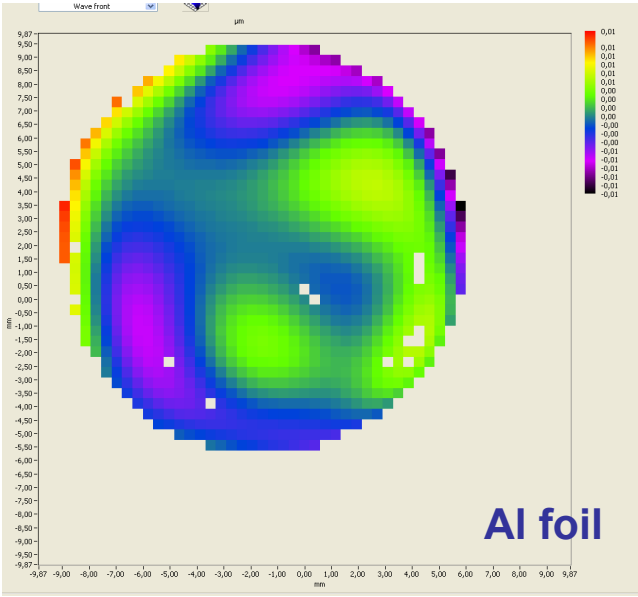
FEL higher harmonics

- up to the 7th harmonic measured
- maximum intensity of second harmonic 1% of fundamental
- filters are required to either make use of these wavelengths or to eliminate any ill effects.



solid filters in BL2

0.2 µm thick Nb foil
0.2 µm thick Si foil
0.1 µm thick Al foil
small wave front modifications @ 27 nm
shorter wavelength maybe worse

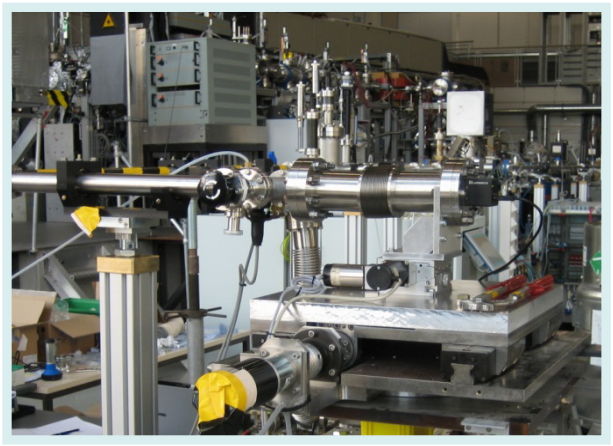


gas absorber

- N_2, Ne and Xe for various wavelengths
- at 27 nm an absorption of 94% by N_2

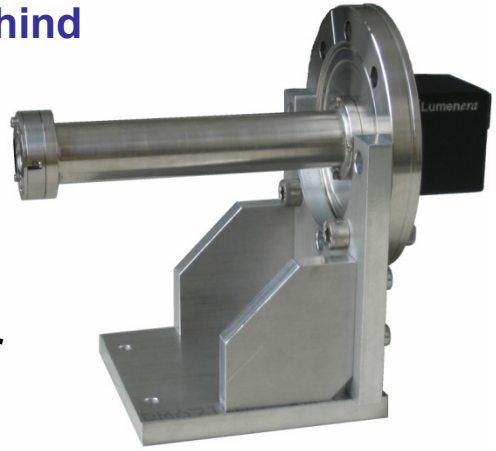
does not change the wave front significantly

Wavefront sensor of Laser Laboratorium Göttingen



Very compact design for use behind user experiments

- **Laser drilled Hartmann plate**
  - **7µm Al-Folie**
  - **YAG @ 1064nm, ~100mJ**
  - **320µm hole pitch**
  - **Approx. 50µm hole diameter**
- **Camera:**



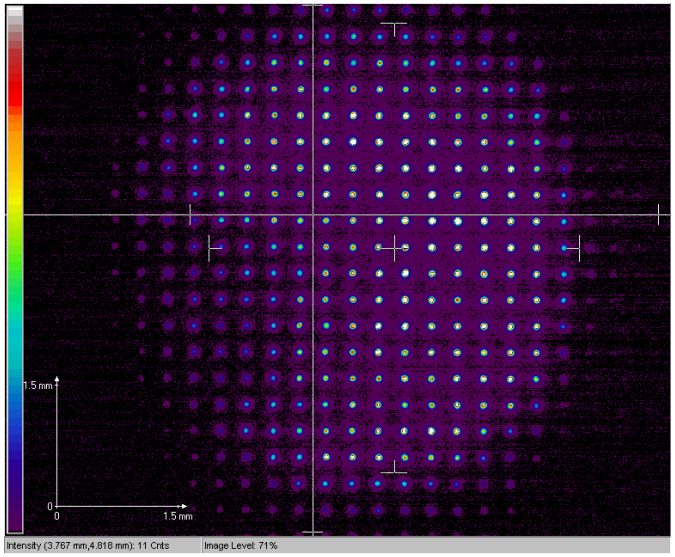
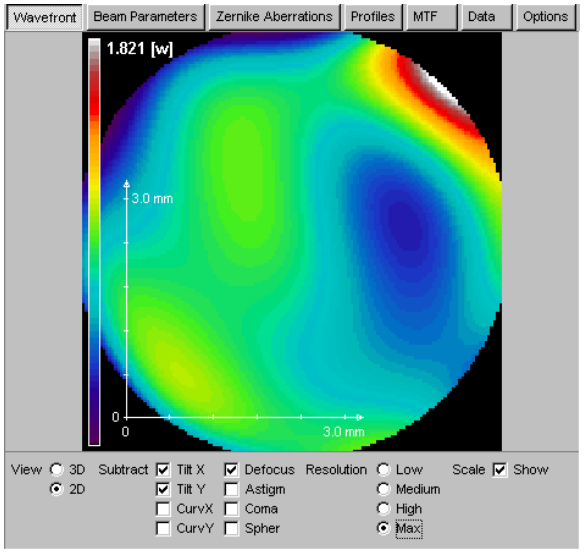


Image on camera



Calculated wavefront

Conclusions

- The wave front sensor proved to be a valuable diagnostic tool for beamline commissioning at FLASH

  BL1 focus: 24 µm (2σ) – 30 µm FWHM

  BL2 focus: 69 µm (2σ) – 86 µm FWHM

- Calibration of WFS is difficult due to need of very small pinholes (low intensities), but calibration holds for years (2005 still valid)
- Alignment of optics is fast
- First order aberrations can be weighted by their origin.

In the near future:

- compact system for users
- gated system for evaluation of effects of long bunch trains
- the use for focal spots below 1 µm must be evaluated
- extend system into X-ray range

The FLASH Team

W. Ackermann, G. Asova, V. Ayvazyan, A. Azima, N. Baboi, J. Bähr, V. Balandin, B. Beutner, A. Brandt, A. Bolzmann, R. Brinkmann, O.I. Brovko, M. Castellano, P. Castro, L. Catani, E. Chiadroni, S. Choroba, A. Cianchi, J.T. Costello, D. Cubaynes, J. Dardis, W. Decking, H. Delsim-Hashemi, A. Delserieys, G. Di Pirro, M. Dohlus, S. Düsterer, A. Eckhardt, H.T. Edwards, B. Faatz, J. Feldhaus, K. Flöttmann, J. Frisch, L. Fröhlich, T. Garvey, U. Gensch, Ch. Gerth, M. Görler, N. Golubeva, H.-J. Grabosch, M. Grecki, O. Grimm, K. Hacker, U. Hahn, J.H. Han, K. Honkavaara, T. Hott, M. Hüning, Y. Ivanisenko, E. Jaeschke, W. Jalmuzna, T. Jezynski, R. Kammering, V. Katalev, K. Kavanagh, E.T. Kennedy, S. Khodyachykh, K. Klose, V. Kocharyan, M. Körfer, M. Kollewe, W. Koprek, S. Korepanov, D. Kostin, M. Krassilnikov, G. Kube, M. Kuhlmann, C.L.S. Lewis, L. Lilje, T. Limberg, D. Lipka, F. Löhl, H. Luna, M. Luong, M. Martins, M. Meyer, P. Michelato, V. Miltchev, W.D. Möller, L. Monaco, W.F.O. Müller, O. Napieralski, O. Napoly, P. Nicolosi, D. Nölle, T. Nunez, A. Oppelt, C. Pagani, R. Paparella, N. Pchalek, J. Pedregosa-Gutierrez, B. Petersen, B. Petrosyan, G. Petrosyan, L. Petrosyan, J. Pflüger, E. Plönjes, L. Poletto, K. Pozniak, E. Prat, D. Proch, P. Pucyk, P. Radcliffe, H. Redlin, K. Rehlich, M. Richter, M. Roehrs, J. Roensch, R. Romaniuk, M. Ross, J. Rossbach, V. Rybnikov, M. Sachwitz, E.L. Saldin, W. Sandner, H. Schlarb, B. Schmidt, M. Schmitz, P. Schmüser, J.R. Schneider, E.A. Schneidmiller, S. Schnepp, S. Schreiber, M. Seidel, D. Sertore, A.V. Shabunov, C. Simon, S. Simrock, E. Sombrowski, A.A. Sorokin, P. Spanknebel, R. Spesyvtsev, L. Staykov, B. Steffen, F. Stephan, F. Stulle, H. Thom, K. Tiedtke, M. Tischer, S. Toleikis, R. Treusch, D. Trines, I. Tsakov, E. Vogel, T. Weiland, H. Weise, M. Wellhöfer, M. Wendt, I. Will, A. Winter, K. Wittenburg, W. Wurth, P. Yeates, M.V. Yurkov, I. Zagorodnov, K. Zapf

This work was partly supported by the **European Community Research Infrastructure** Action under the FP6 “Structuring the European Research Area” Programme through the Integrated Infrastructure Initiative **“Integrating Activity on Synchrotron and Free Electron Laser Science”**, contract number RII3-CT-2004-506008.

FLASH experimental hall