New wavefront sensor for renewed differential pumping unit at FLASH2 beamlines

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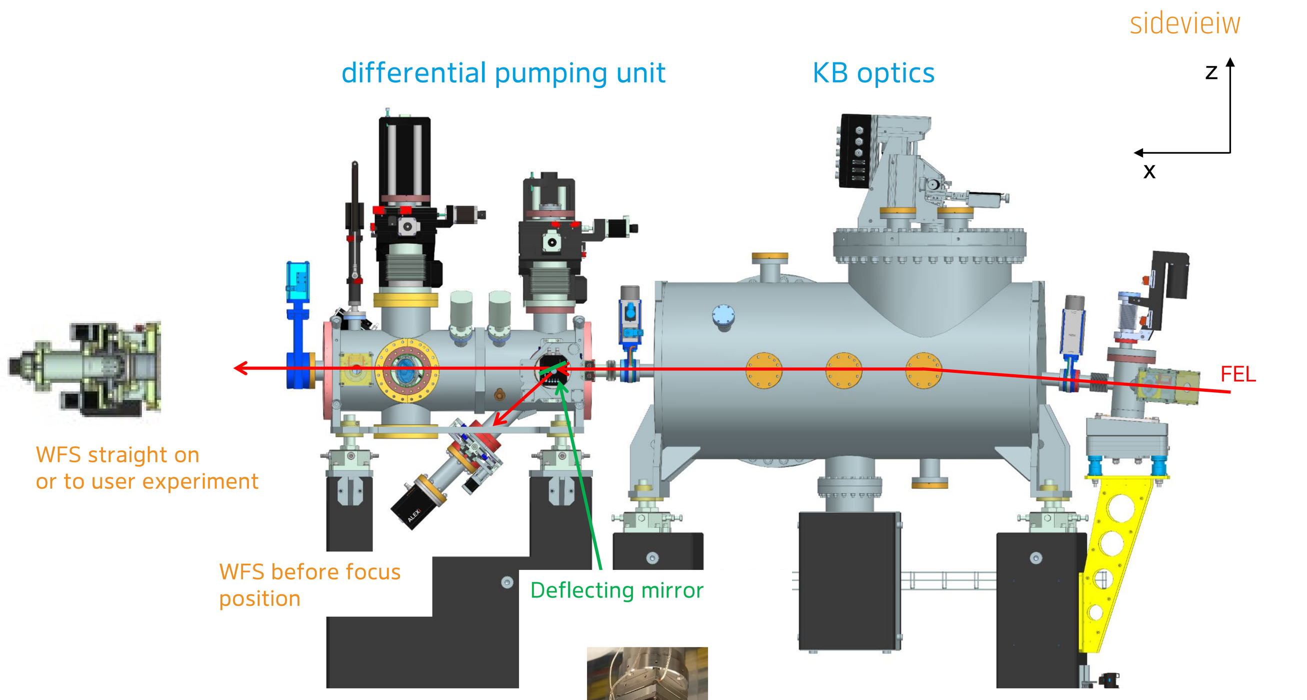
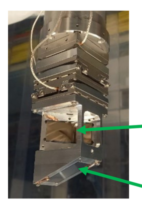
Permanent wavefront sensing setup incorporated at beamline FL23 and in future at FL24

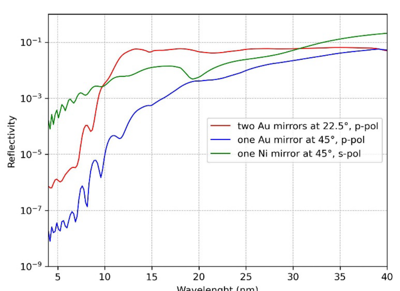




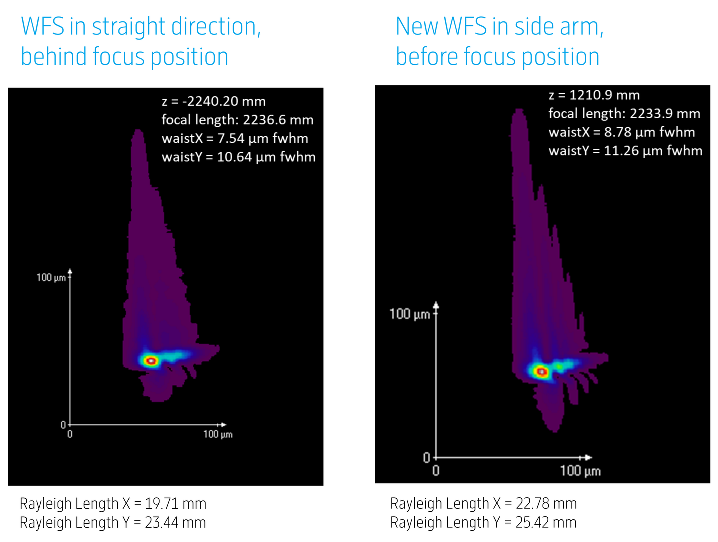
- one Au mirror at 45° reflects FEL sideways to a WFS in horizontal plane used for long wavelengths up to 60 nm
- one Ni mirror at 22.5° reflects FEL down to WFS for shorter wavelengths (4 – 30 nm)
- Mirror size 40 mm x 20 mm
- Mirror holder with 3-axis pico-motor rotation in x, y, z is mounted on a 3-axis movable manipulator (translation in x, y, z) to position the beam onto the Hartmann plate

New design:

- need to incorporate WFS into every beamline using bendable KB optics
- design benefits and limited space around the differential pumping unit let the newly build WFS be located under 45° beneath the differential pumping unit
- use of s-polarized light with one Ni mirror under 22.5° incidence angle for short wavelengths up to 30 nm, increase of intensity
- use of p-polarized light with one Au mirror under 45° incidence angle for wavelengths up to 60 nm
- WFS is located before focus position to avoid a large arm

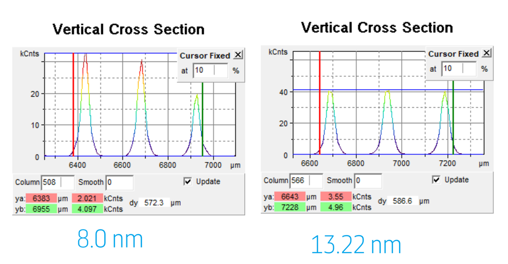


Both monochromators at FL23 in zeroth order



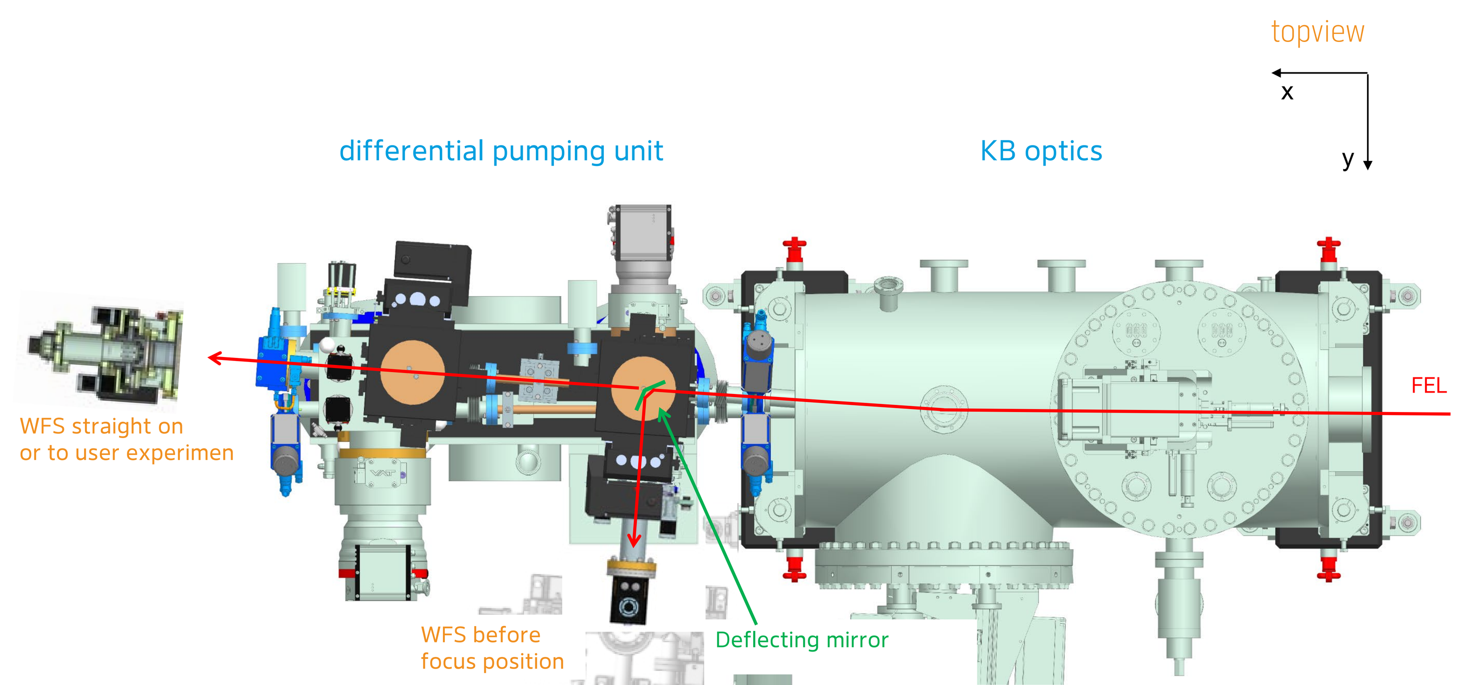
13.22 nm

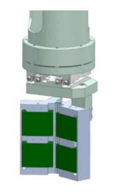
Well separated Gaussian shaped spot from the Hartmann plate.



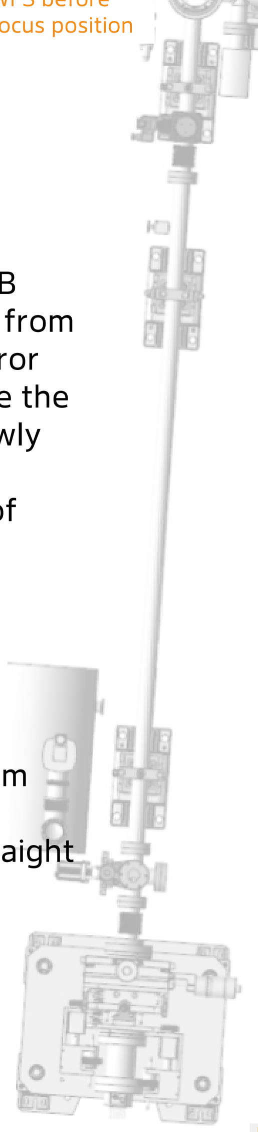
Deviation of waist position determined by WFS in front and after the focus is around 3 mm. Horizontal waist diameter differs by 1.24 µm whereas the vertical waist diameter is only different by 0.6 µm.

Present wavefront sensing setup at FL24



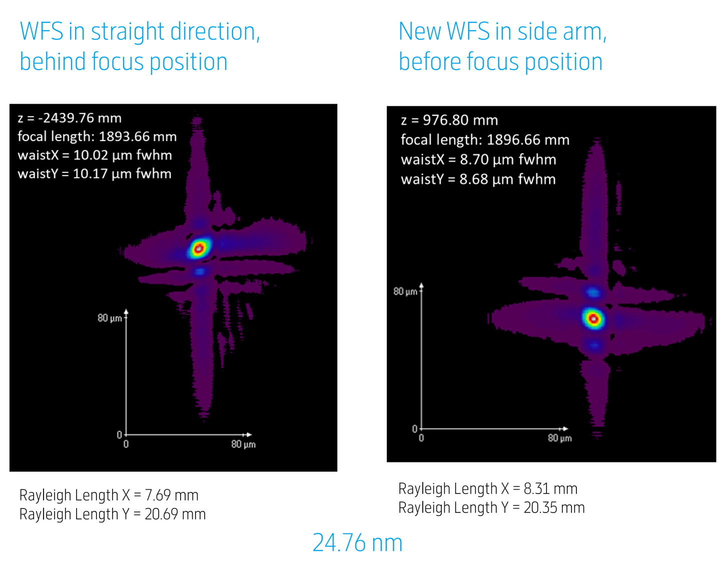


- two Au mirrors each at 22.5° incidence angle reflect FEL sideways to the WFS in horizontal plane
- Mirror size 32 mm x 25 mm
- Mirror holder mounted on a 3-axis movable manipulator (translation in x, y, z) to position the beam onto the Hartmann plate; including a goniometer to rotate around the bisecting angle between x and y



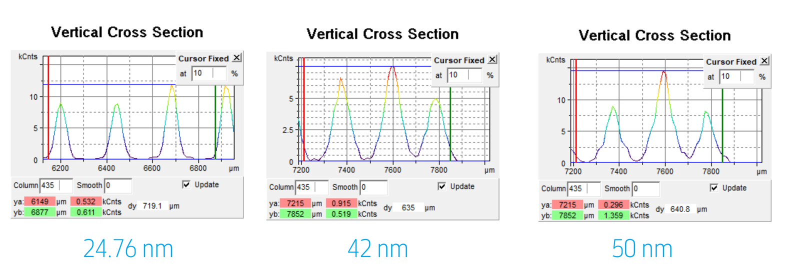
Successful first proof-of-principle demonstrator:

- WFS in the side arm for alignment of KB optics without disturbing users moved from 5172 mm behind the horizontal KB mirror (after focus position) to 920 mm before the focus position to not interfere with newly installed beamline FL23
- two Au mirrors at 22.5° used instead of one at 45° to increase output for p-polarized light
- limited wavelength range due to poor reflectivity of Au mirror for p-pol. light below 8 nm
- depending on wavelength and beam diameter, focus positions between 1.5 m and 3.5 m can be measured
- conform results in the side arm and straight direction for the new WFS position

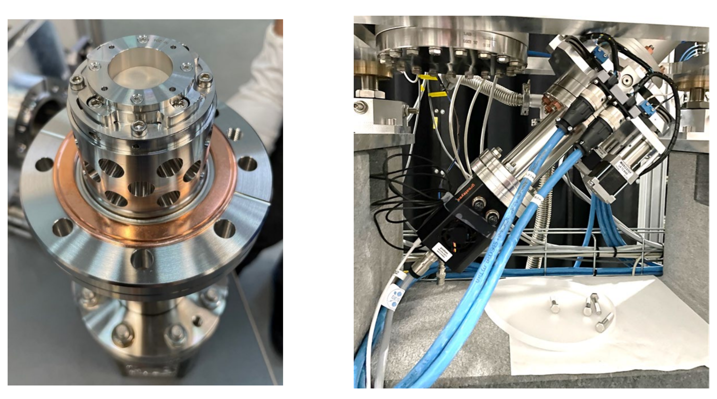


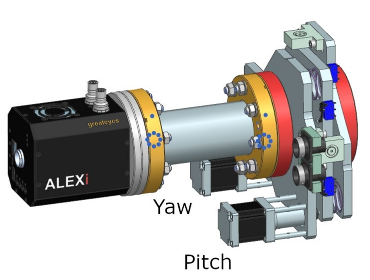
24.76 nm

Wavelength was changed up to 50 nm to test upper wavelength limit for the new wavefront sensor. For 42 nm and 50 nm the cross sections of the spots from the Hartmann plate are not Gaussian shaped any more and spots are not clearly separated.



New wavefront sensor





Spectral range: 4 nm – 30 nm

Hartmann plate:

- 10 µm Ni foil with electroformed holes in a squared grid
- hole diameter 100 µm, pitch 300 µm
- closed hole in the center for alignment purpose

ALEXi 1k1k BI UV1 CCD:

- field of view: 13.73 mm (H) x 13.35 mm (V)
- back-illuminated 18 bit dynamic range CCD for VUV spectral range
- 1056 (H) x 1027 (V) pixels with 13 µm x 13 µm pixel size
- 0.33 Hz operation

Plate – CCD Chip: 200.1 mm
Wavefront repeatability for w_{rms}@ 13.5nm: ~λ/103

Motorized tip/tilt stages: ± 5°

Software MrBeam written by IFNANO (including propagation of beam profiles with selectable degree of coherence in x and y direction)

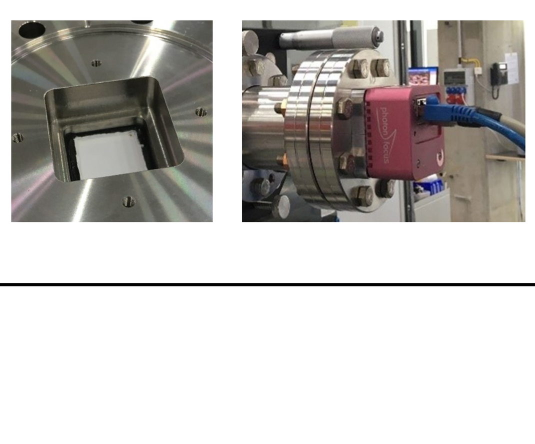
Conclusion and outlook

It could be shown that the adjustment of KB optics as well as the determination of the focus size and position is possible using a wavefront sensor after the focus position (WFS straight on) and before the focus position (FL23 at 45° and FL24 at 90°). Both wavefront sensors provide comparable results. FL23 is the newly installed pulse-length preserving double monochromator beamline at FLASH2.

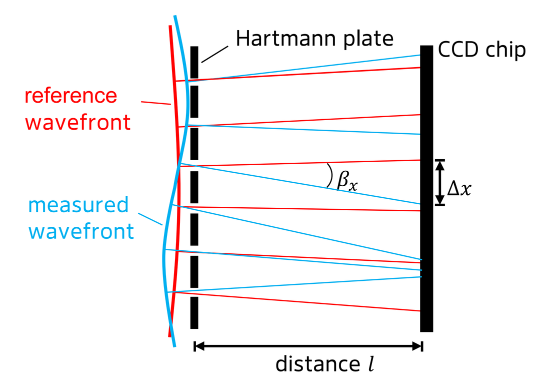
The next step is to build a wavefront sensor for longer wavelengths up to 60 nm by using a Hartmann plate with holes of 100 µm diameter and a pitch of 500 µm. This WFS will be mounted horizontally on the pressure stage at 90° to the beam and uses the Au mirror.

Photonfocus A2080 (MV1-D2080-160-G2-12-CM):

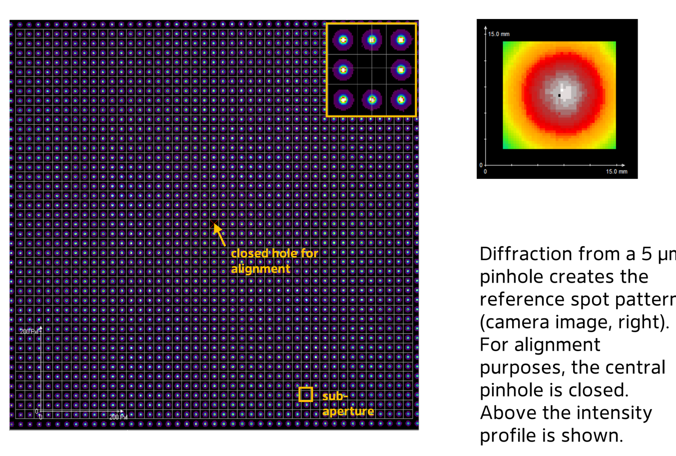
- field of view: 16.64 mm (H) x 16.64 mm (V)
- 4/3" CMOS NIR enhanced with phosphor P43 coating
- back-illuminated 18 bit dynamic range CCD for VUV spectral range
- 2080 (H) x 2080 (V) pixels with 8 µm x 8 µm pixel size
- 5 Hz operation
- GigE interface



WFS operation principle



Spot pattern of the reference wavefront



Diffraction from a 5 µm pinhole creates the reference spot pattern (camera image, right). For alignment purposes, the central pinhole is closed. Above the intensity profile is shown.

The wavefront of a beam is defined as a surface perpendicular to its local direction of propagation at a position z_o on the optical axis (ISO 15367-2:2005).

A Hartmann wavefront sensor consists of a pinhole array and a CCD camera in a certain distance l. The incident wavefront illuminates the pinhole array and each pinhole focuses the local wavefront onto the CCD. Without any aberration, the CCD image would be a perfect array of regular spots (red), e.g. the calibration wavefront.
If the wavefront is distorted, each spot moves away from its ideal position (blue).
By measuring for each spot centroid position the displacements $(\Delta x, \Delta y)$ from the ideal reference spot centroid position and divided them by l, the local angles β_x, β_y and the local wavefront gradients (slopes) in each sub-aperture can be determined. For spherical beam profiles the entire incident wavefront $w(x,y)$ is reconstructed from the local gradients by a modal approach and a least-squares fit using Zernike or Legendre polynomials and afterwards correct for tip/tilt and defocus. This is used to determine the aberrations, i.e. the Zernike polynomials.

Summation over all pixel values inside the individual sub-aperture yields the intensity distribution or beam profile $I(x,y)$. The knowledge of the intensity profile and the local wavefront slopes allows calculation of beam parameters using the moments method. The following beam parameters can be calculated:

- beam width
- divergence
- beam waist diameter
- beam waist position
- beam propagation factor M^2
- Rayleigh length

Numerical propagation

Once the intensity and phase are known from the measurements, the Fresnel-Kirchhoff propagation yields the intensity distribution at different propagation distances z_0,

$$I(x,y;z_0) = \left| \frac{ik}{2\pi z_0} \iint_{\infty} \sqrt{I(x',y')}\, e^{ikw(x',y')} \cdot e^{\frac{ik\left[(x-x')^2 + (y-y')^2\right]}{2z_0}} dx'dy' \right|^2$$

where x', y' and x, y are the Cartesian coordinates in two coplanar planes, separated by z_0. Spatial degrees of coherence are also included using the Gaussian and Bessel correlation.

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