

THE ATHOS SOFT X-RAY BEAMLINES AT SwissFEL

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Abstract

SwissFEL is a free electron laser facility for hard and soft X-rays at the Paul Scherrer Institut in Switzerland. The hard X-ray FEL ARAMIS started 2016 with the first experiments and now the soft X-ray FEL named ATHOS is close to completion with the first light being expected in 2019. ATHOS will cover the photon energy range from 250 eV to 1900 eV with pulse energies up to 8 mJ. It will operate with three end stations. Two stations are already defined and are currently in the design and construction phase. MALOJA, the first station, is dedicated to Atomic and Molecular physics as well as nonlinear spectroscopy. It will get first light in mid 2020. The second station, FURKA, is for condensed matter physics and will go online in 2021.

The performance of the beamline was already presented in an earlier paper [1], here we report on the various operation modes and the latest changes in the optical design.

ATHOS SOURCE

In standard operation mode SwissFEL generates double electron bunches with a separation of 28 ns at a repetition rate of 100 Hz and accelerates them in the first part of the main LINAC. Afterwards one of the double bunches stays in the main LINAC and is further accelerated up to 5.9 GeV before entering the ARAMIS undulator. The other bunch is extracted from the main LINAC at beam energies between 2.9 GeV and 3.15 GeV and sent to the ATHOS LINAC where the electron energy is modified between 2.65 GeV and 3.4 GeV before it enters the ATHOS undulator. By this, both FELs can operate independently and at a repetition rate of 100 Hz. The ATHOS undulator consist of 2 m long APPLE-X [2] modules in a FODO lattice with 2.8 m period length. Each APPLE-X module is composed of 50 magnet periods with a period length of 38 mm. By tuning the electron beam trajectory it is possible to lase with the tail part of the electron bunch in the first section and with the head part in the second undulator section. The time delay between both pulses can be tuned between -50 fs to +950 fs. The photon wavelength of each undulator section can vary within the tuning range of the undulators ($K = 1 \dots 3.5$) while the working point is determined by the electron beam energy.

The FEL was optimized with the help of GENESIS [3] and foresees several operation modes e.g. high power, low bandwidth or two color modes. The pulse length is about 30 fs (rms), with the ability to reduce it below 1 femtosecond in the attosecond mode.

For the beamline design the high power and two color mode are the most relevant. In the high power mode a maximum pulse energy together with the least photon beam

divergence result in the highest fluence values. This must be considered in the optical layout to avoid single shot damage of the optical elements. In the two color mode the undulator is divided into two sections, each 25.2 m long, with individual k-values where both sections can lase at different wavelengths. The larger photon beam divergence together with the long distance from the first undulator section to the optical elements produce the widest beam cross section at the optical elements and determines the geometrical dimensions of the optical elements. Table 1 summarizes the beam parameters for the largest divergence and the highest fluence.

Table 1: Beam Parameters for the ATHOS Undulator UE38

Photon energy	(eV)	250	250
Mode		power	2 color
Source size*	(μm)	39.6	30.4
Source divergence*	(μrad)	19.8	25.8
Pulse energy	(mJ)	8.1	2.35
Spectr. bandw.*	(%)	0.9	0.57
Source position	(m)	-15.6	-3.9/ -29.1
Beam size* in 73 m (mm)		1.8	1.9/2.6

*rms-values

BEAMLINE

The ATHOS beamline is based on a common grating monochromator and distributes the beam afterwards by means of horizontally steering mirrors to three branches. Its overall scheme is shown in Figure 1. The first, horizontally deflecting mirror separates the FEL-radiation from the Bremsstrahlung that is absorbed in the subsequent radiation shielding. The mirror itself is bendable with a surface profile between flat and a meridional radius of 5000 m. It can either produce an intermediate horizontal focus nearby the exit slit for the MALOJA-branch or set to flat for an undisturbed beam divergence. An intermediate focus allows for a gas based diagnostic unit with small apertures after the monochromator to derive an intensity signal of the monochromatized beam.

The monochromator uses variable line-space gratings on spherical substrates with a variable included angle in a SX-700 geometry [4] and operates without an entrance slit. By mounting the optics in a SX-700 mechanics a vertical beam offset of 9 mm between the incoming and outgoing beam is introduced. The setup of mirror and gratings is reverted with respect to the original setup [5] and the plane mirror is now facing downwards whereas the gratings are oriented face upwards. By this the deflection angle on the plane mirror can be reduced while maintaining a larger deflection angle at the gratings. This results in an slightly upward pointing

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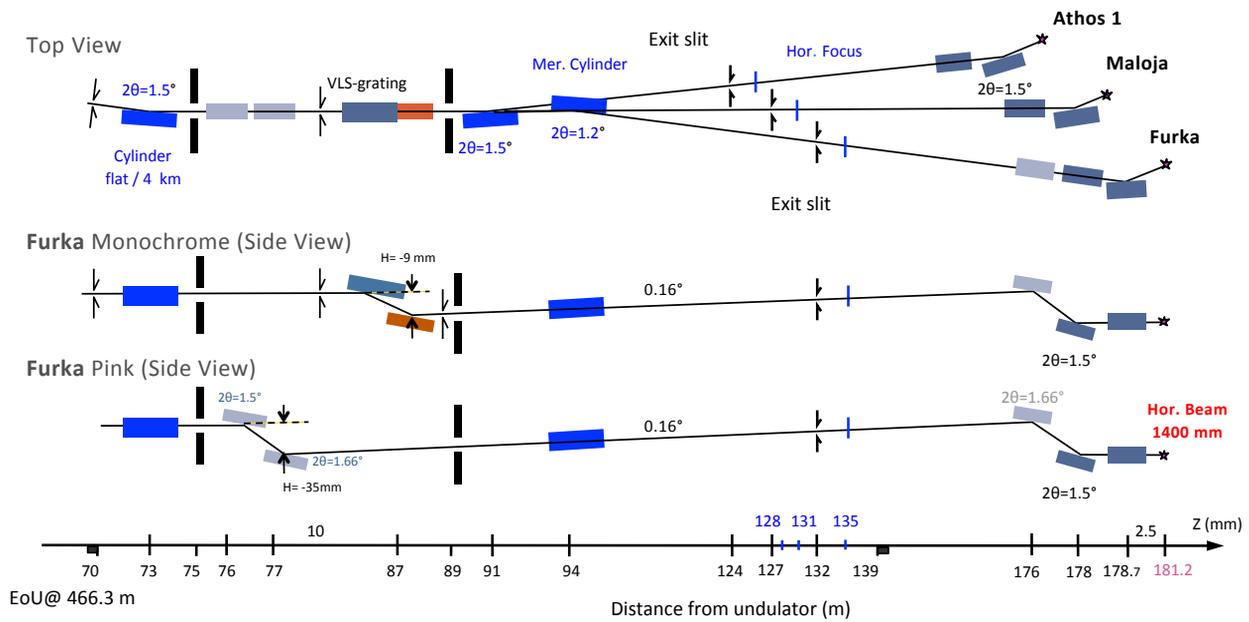


Figure 1: Optical layout of the ATHOS beamlines. Top view of all three branches and side view of the Furka branch in monochrome and pink mode, respectively.

diffracted beam. The upwards pointing diffracted beam is due to a boundary condition set by the FURKA end station, that needs a beam height of 1.4 m while the accelerator has a beam height of 1.2 m. MALOJA does not set this boundary condition and operates with a horizontally diffracted beam.

The gratings and the plane mirror can be moved aside to let the undispersed FEL beam pass towards the end stations.

After the grating chamber the beam is distributed to the branches ATHOS 1 and FURKA by means of two horizontally deflecting and focusing mirrors. The central MALOJA branch omits such a mirror and stays in the direct line. By this a reasonable lateral separation of all three branches is obtained. All three end stations are staggered at different distances from the source in separate enclosed areas of the building.

Each branch has an own exit slit and a dedicated KB-refocusing optics. The KB-systems are modified versions of the KB-system at ARAMIS, mainly with a larger deflection angle. Pink and monochromatic beam operation with the same pointing to the experiment is foreseen for all branches.

Monochromator

The grating chamber hosts two cylindrical gratings with line densities of 50 l/mm and 150 l/mm. The low line density grating has a patterned length of 130 mm, a meridional radius of 8 km and a blaze angle of 0.15°, whereas the high line density grating has a laminar profile, a radius of 10 km and a patterned length of 280 mm. This is due to limitations of the current grating technology that allows blazed gratings only up to a length of 130 mm. Both gratings have a variation in the line density in the order of 10^{-5} l/mm.

Very shallow incidence angles on both gratings are mandatory to reduce the risk of single shot damage. The low line density grating is therefore operated in outside diffraction or-

der, while the high line density grating is operated in inside diffraction order. Both gratings will have the bulk silicon surface for low photon energies and a coating for higher photon energies. The change between both areas is achieved by a lateral translation and does not affect the focal properties.

The gratings disperse the beam and focus it vertically onto the exit slits. The included angle on the gratings can be set by the plane mirror to maintain the focal condition for all photon energies, all three exit slit distances and for the two inclination angles of the diffracted beams in FURKA and MALOJA. Even a – known – variable source distance can be taken into account by the software control.

FURKA

Furka is the right branch of the beamline. Most probably, the monochromatic mode will be the main operation mode. In this mode, the FEL beam deflected from the first mirror enters the grating chamber horizontally. The grating disperses and focuses the dispersed beam vertically onto the exit slit. As the end station is quite large, the beam height must be increased from 1.2 m in the accelerator to 1.4 m at the end station. This can be accomplished by increasing the deflection angle on the grating with respect to the one at the plane mirror by 0.16°. The horizontally steering mirror at 94 m is therefore inclined by the same angle.

In pink mode the grating is retracted and two vertical offset mirrors at 76 m and 77 m bring the beam onto the same trajectory as in the monochromatic mode, at least downstream of the grating. The steering mirror can therefore stay in the same orientation as in pink mode. Between the first offset mirror at 76 m and the grating at 87 m the trajectories in pink and monochromatic mode differ vertically by a value between 0 mm and 35 mm.

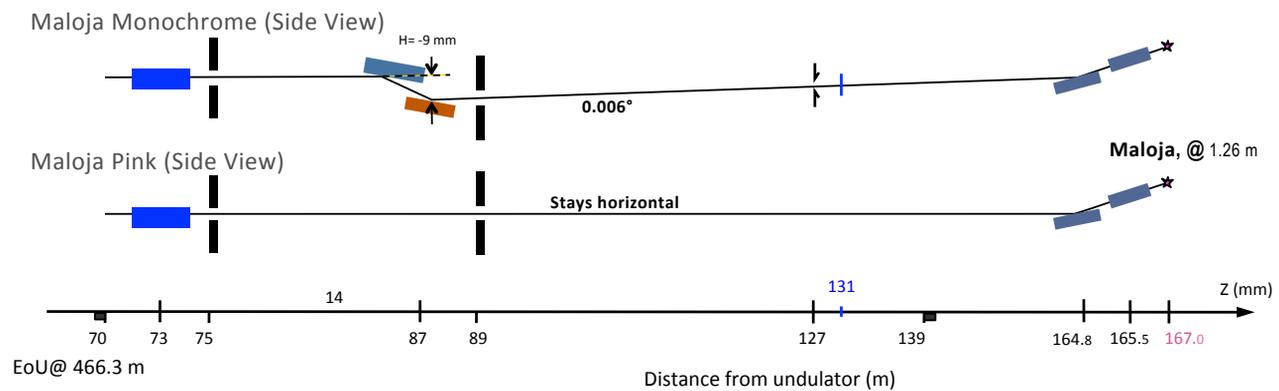


Figure 2: Optical layout of the ATHOS beamlines. Side view of the MALOJA branch in monochrome and pink mode, respectively.

An additional boundary condition set by the FURKA-experiment is a horizontal beam trajectory in the experimental chamber. For this an additional vertical deflecting mirror in front of the KB-mirrors is foreseen. It deflects the beam downward to the KB, which finally brings it back to the horizontal.

Unfortunately, the upgoing angle of the diffracted beam after the grating can not be increased to the deflection angle of 1.5° on the KB-system. This would have been a nice option to omit the deflecting mirror at 176 m.

MALOJA

The central branch with the MALOJA end station (Fig. 2) is optimized for pink beam operation with the least number of optical elements. In pink beam operation the first mirror is set to flat and deflects the beam directly to the KB-system. The exit slits must be opened to pass the unfocused beam. By this configuration the large demagnification ratio allows for a nominal focus size of $1 \mu\text{m}$ in a distance of 1.5 m from the center of the last mirror. In monochrome mode the first mirror can produce an intermediate horizontal focus nearby the exit slit for the gas based intensity monitor with small apertures. The change in source distance of the subsequent KB-system is compensated by a proper bending of the horizontally deflecting KB-mirror.

The beam in this branch stays horizontal at a height of 1200 mm until the KB-system. Afterwards it has an upgoing angle of 1.5° towards the experiment.

In monochrome mode, the grating and plane mirror are introduced and the exit slit closed to $20 \mu\text{m}$ – $200 \mu\text{m}$. To compensate the beam offset within the grating chamber the beam trajectory between grating and the deflecting KB-mirror is different from the pink mode by an angle of 0.006° with a maximum vertical separation of 9 mm. The vertically deflecting KB-mirror stays at the same height, but the deflection angle is slightly changed to guarantee the same pointing as in monochrome mode.

Outlook

The installation of the beamline components started in the front end where first light is expected for December 2019. The first pink beam in MALOJA is expected for April 2020. The mirror mechanics of the first and second mirror chambers are currently assembled in house while the first mirror from Jtec is expected for January 2020. The KB-system for MALOJA from Toyama and Zeiss is expected for the end of the year, while the monochromator and its optical elements, as the most complicated components, are in fabrication at Bestec and Jtec. Their delivery and installation is expected for end of 2020.

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