

# TECHNICAL DESIGN OF THE XUV SEEDING EXPERIMENT AT FLASH\*

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## Abstract

The Free-electron-laser at Hamburg (FLASH) operates in the Self-Amplified Spontaneous Emission (SASE) mode, delivering to users photons in the XUV wavelength range. The FEL seeding schemes promise to improve the properties of the generated radiation in terms of stability in intensity and time. Such an experiment using higher harmonics of an optical laser as a seed is currently under construction at FLASH. The installation of the XUV seeding experiment (sFLASH) is going to take place in fall 2009. This includes mounting of new variable-gap undulators upstream of the existing SASE-undulators, building the XUV-seed source as well as installation of additional photon diagnostics and electron beam instrumentation. In this contribution the layout of sFLASH will be discussed together with the technical design of its major components.

undulators. With the help of a dedicated optical beamline, the HHG seed will be inserted through the collimator section, making use of the electron beam offset of about 20 cm. After amplification in the sFLASH variable-gap undulators, the output radiation is separated from the electrons by means of a mirror mounted in a small magnetic chicane downstream. The photons are then reflected towards the experimental area outside the FLASH tunnel. An experiment recently performed by a French-Japanese collaboration at the SPring-8 Compact SASE Source [3] has successfully demonstrated HHG seeding at 160 nm. The goal of sFLASH is to study the technical feasibility of the seeding at shorter wavelengths and how to reliably realize it for user operation.

## INTRODUCTION

Currently FLASH operates in the SASE regime and produces EUV pulses of sub-10 fs duration [1]. Due to its start-up from noise, the SASE radiation consists of a number of uncorrelated modes resulting in reduced longitudinal coherence and shot-to-shot fluctuations (about 18 % rms [1]) of the output pulse energy. One possibility to decrease the magnitude of these pulse energy shot-to-shot fluctuations is, with the help of a 3.9 GHz RF cavity [2], to produce much longer ( $\sim 200$  fs) radiation pulses, so that more modes contribute to the FEL output. However, in this case the increased EUV pulse length might not fit to the needs of ultrafast time resolved experiments. An alternative is to operate FLASH as an amplifier of an injected seed from a high harmonic generation (HHG) source. This approach gives several benefits compared to SASE. It enables to achieve higher shot-to-shot stability at a GW-power level with a pulse duration given by the seed pulse of the order of 20 fs FWHM. The longitudinal coherence is expected to be greatly improved. The FEL output is synchronized with the external seed laser, thus enabling pump-probe experiment with increased temporal resolution.

As sketched in Fig.1, sFLASH will be installed at the end of the linac, upstream of the existing fixed-gap SASE-

## ELECTRON BEAMLINE

### General Requirements

The aim for a stable seeded operation in the 30-13 nm range imposes certain requirements for the design of the experimental layout and for the electron beam parameters. It is mandatory to obtain a reproducible six-dimensional,  $\{x, y, x', y', t, \lambda\}$ , overlap between the seed and the electron bunch. Therefore, the beamline must include proper diagnostics and instrumentation to maintain the overlap within the desired tolerances, which according to the studies performed with GENESIS [4, 5], are of the order of  $30 \mu\text{m}$  and  $20 \mu\text{rad}$  in both transverse planes. In order to minimize the impact of the timing jitter, the electron bunch length should be of the order of 260 fs rms, even though the state-of-the-art synchronisation system (see below) can restrict the jitter to less than 40 fs rms. Such operation mode can be realized only after the installation of the 3<sup>rd</sup> harmonic (3.9 GHz) RF cavity. sFLASH has to run in parallel to and without disturbing the SASE operation. The SASE-undulators are fixed-gap devices and the SASE wavelength, given by the electron energy, is defined by the users. Therefore, for tuning the resonant wavelength of sFLASH one needs variable gap undulators. Moreover, the total undulator length has to assure that saturation can be reached at all seeding wavelengths. Finally, since the HHG seeding will share the same beamline with other setups (e.g. ORS [6] and LOLA[7]), one has to provide compatibility between the different experiments.

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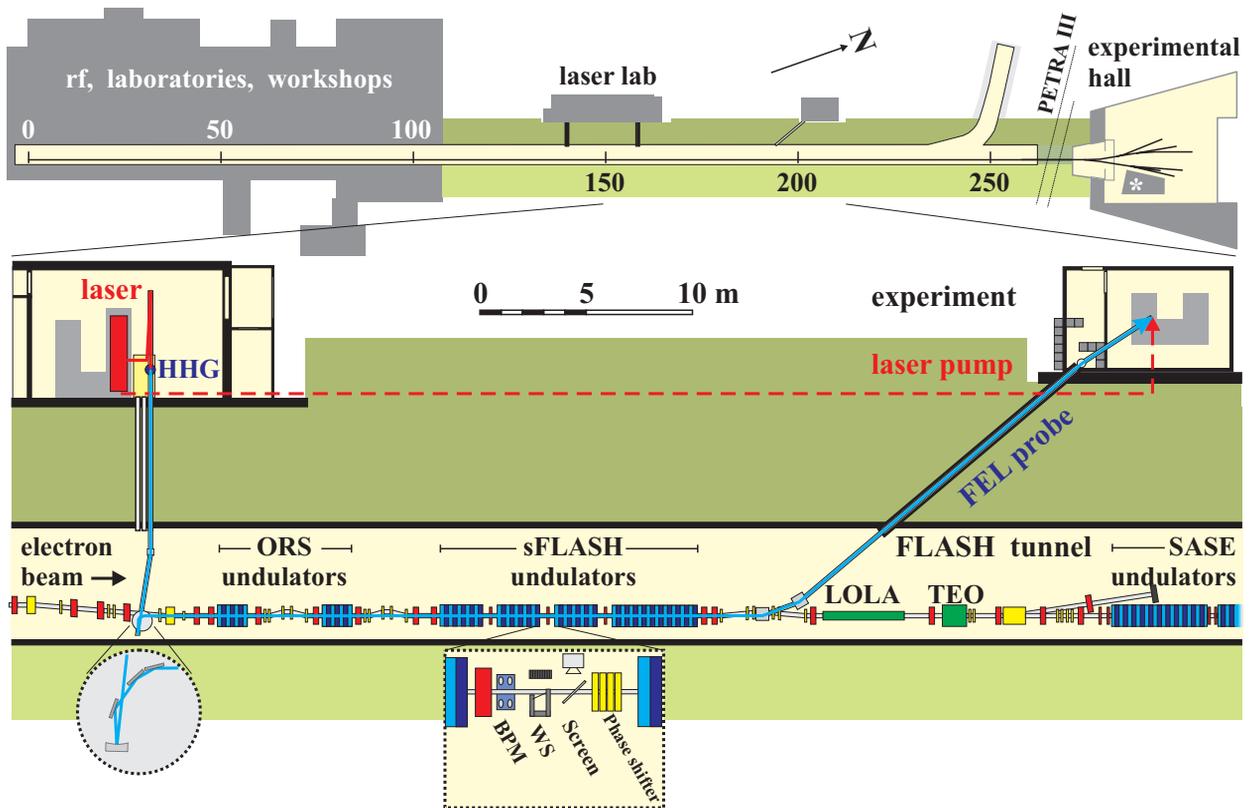


Figure 1: The FLASH facility (top) comprises a 260 m long tunnel housing the linac and the SASE-undulators, followed by an experimental hall. A 40 m long section (bottom) upstream of the SASE-undulators will be modified in order to install beam line components for the XUV seeding experiment. Seed pulses from the HHG source in the building adjacent to the FLASH tunnel will be aligned to the electron beam downstream of the last dipole of the energy collimator (left). At the undulator exit, the FEL radiation is reflected towards an experimental hutch. A fraction of the optical drive laser energy will be sent directly to the hutch for pump-probe applications (dashed line). The dashed bordered boxes show detailed views of the seed incoupling and the undulator intersections.

### Beamline Layout

The final layout of the electron beamline in the seeding section is illustrated in Fig.2. It consists of four planar variable-gap undulators of 10 m total length, separated by 70 cm intersections. As shown in Fig.3, the transverse focusing, accomplished by quadrupoles placed in-between the undulator segments, allows an average  $\beta$ -function of the order of 6 m. The electron beam diagnostics will be realized using wire scanners, optical transition radiation (OTR) and Ce:YAG screens and beam position monitors. The wire scanners and screen stations, together with additional instrumentation (BPM, microchannel plates), will be compacted in a common diagnostic block. The idea is to make these devices usable for both electron beam and HHG radiation diagnostics. This feature is critical for finding and keeping the overlap between electrons and the seed. From this point of view the two diagnostic blocks located before and after the first undulator (see Fig.2) are of particular importance. The three electromagnetic phase shifters will compensate the shift between the phase of the electron transverse velocity and the electromagnetic field, in-

duced by the drift between undulators. Figure 3 shows the  $\beta$ -function along the seeding beamline calculated with the help of the code ELEGANT [8]. The apertures of both

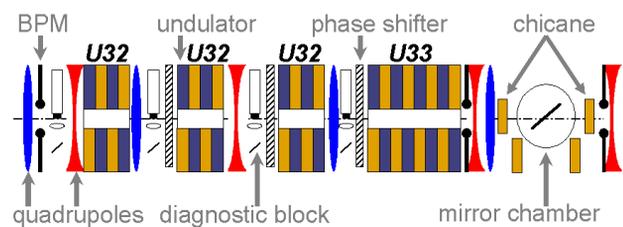


Figure 2: Schematic layout of the electron beamline in the seeding section.

the collimator (located upstream of the sFLASH undulators, see Fig.1) and the vacuum chamber have been considered in the design of the electron optics in order to assure full transmission without losses.

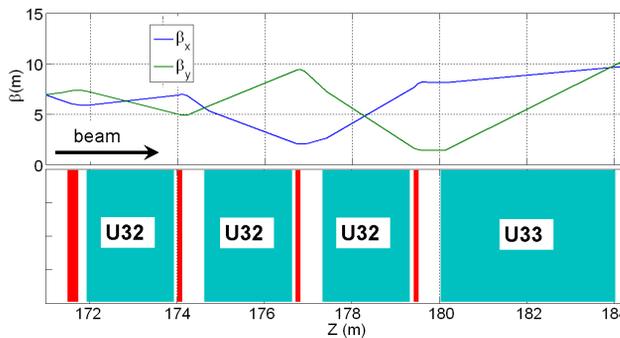


Figure 3:  $\beta$ -function along the sFLASH beamline

### sFLASH Undulators

As sketched in Fig.2 sFLASH comprises a 10 m long undulator section. Unlike the present FLASH undulators, these will be variable gap devices. Three 2 m long U32 will be followed by a 4 m long U33 undulator. The latter is a previously decommissioned device which can be reused for sFLASH after refurbishment as described elsewhere [9]. In Table 1 undulator parameters are listed. The

Table 1: Parameters of sFLASH Undulators [9]

	U32	U33
Min. gap (mm)	9.0	9.0
Period length (mm)	31.4	33
No. of poles	120	240
Length (m)	2	4
Peak field (T)	1	1.07

sFLASH undulator chamber uses a modification of the European XFEL design [9] (see Fig. 4). Taking into consideration the vertical size of the vacuum chamber (8.6 mm) and the minimum desired undulator gap size (9 mm), a sophisticated support and holder system is prepared to adjust and maintain the position of the chamber within the undulator gap. The development of undulators for PETRA III [10]

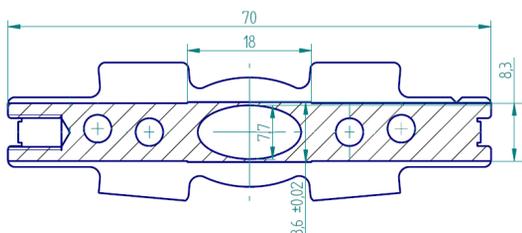


Figure 4: Cross-section of the undulator vacuum chamber

has been adapted for U32 undulators. Their control system is based on off-the-shelf standard components for industrial automation. The gap drive consists of two independent servo axes for each magnet girder to allow for maximum flexibility, e.g. for tapering or beam height adjustment. Each of the axes is equipped with a multi-turn absolute rotary encoder to provide operational reliability even after a

loss of power. In order to achieve the desired accuracy of the order of  $\pm 1 \mu\text{m}$ , additional linear encoder systems will be mounted at the up- and downstream end of the magnet girders.

The U33 undulator was disassembled in 2007 after more than 10 years of operation in the PETRA II ring. The mechanics, used for this undulator, was originally developed for the DORIS III wigglers. Its gap measurement system was based on a rotary encoder connected to one of the gearboxes. Since neither a real-gap measurement system nor a feed-back loop for the gap were available, the undulator motion control has been upgraded. Four displacement gauges with micrometer precision were installed at the corners of two jaws. In this design a real-gap measurement tool will be used to reach the same level of accuracy as described for U32s (see [10]).

### LASER SYSTEM, HHG SOURCE AND BEAMLINE

HHG occurs when an intense laser field interacts with an atomic gas target. The sFlash seeding source gas target supplied by a pulsed valve is driven by short (35 fs FWHM) 800 nm pulses at a repetition rate of 10 Hz produced by a Ti:sapphire laser system. Depending on different beam focusing schemes, a fraction of the 35mJ pulse energy will be sent into the HHG target chamber. The remaining energy will be used for pump-probe and electron bunch diagnostic applications. XUV radiation will be created in the gas jet [11] and transported through a differentially pumped vacuum pipe from the laser laboratory into the adjacent FLASH tunnel. Here a small diagnostic unit first filters and detects the position of the higher harmonics. After that two UHV chambers, holding mirrors with different UV coatings (optimized for  $\sim 30 \text{ nm}$  and  $\sim 13 \text{ nm}$ ), deflect and focus the beam to guide it onto the electron beam axis [12]. To adjust the transverse overlap (angle and position) between the XUV and the electron beam all mirrors are motorized. In addition, they are mounted on translation stages to switch between the coatings and - for the focusing mirror - different radii of curvature. To enable a longitudinal overlap between the electron bunches and the XUV pulses the laser system will be synchronized with the laser master oscillator of FLASH by an optical synchronization system currently being installed [13]. Together with an intra-pulse train feedback system for the accelerator one expects a relative jitter between the two pulses in the order of 40 fs (rms).

### SEPARATION OF PHOTONS AND ELECTRON BEAM

At the exit of the undulator section a magnetic chicane separates the electron and the photon beam vertically. The radiation is directed into a grazing incidence spectrometer using a set of amorphous carbon coated Si plane mirrors that exhibit very high radiation stability [14, 15]. The reflectivity of the optics at grazing angles of  $5^\circ$  is typically

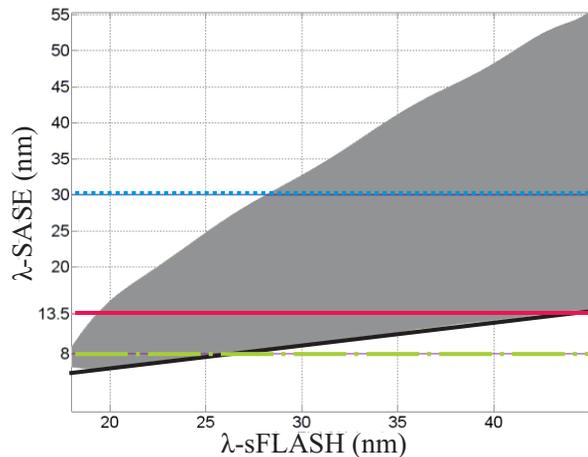


Figure 5: The grey area represents the working points where sFLASH reaches saturation for a given set of FLASH SASE-wavelengths and sFLASH-wavelength. A seed pulse energy of 1 nJ is assumed.

larger than 85 %. The spectrometer (McPherson 248/310G, 1-meter focal length, [16]) incorporates an entrance slit adjustable from 5 to 500  $\mu\text{m}$  in front of the gold coated grating with 1200  $\text{grooves}\cdot\text{mm}^{-1}$ , blazed at 20 nm and 3° angle of incidence. The 40 mm microchannel plate detector assembly is mounted perpendicular to the exit beam of the instrument tangent to the Rowland circle. This way the spectra can be recorded on a single-shot basis with large dynamic range. Data readout is done by a fibre taper connected to a CCD. The CCD can be scanned along the Rowland circle to position any wavelength between 1 nm and 35 nm at the centre of the detector. The array-detector equipped system will provide approximately  $\lambda/\Delta\lambda = 1000$  at 13 nm and 30 nm wavelength position. Finally, the undulator gap is tuned so that the undulator radiation and the seed are spectrally matched in the spectrometer. The photon beamline design allows for switching the light between the spectrometer branch and the experimental hutch. Here, the FEL radiation is combined with part of the naturally synchronized optical seed to study the robustness of a seeded FEL at XUV wavelength and the feasibility of dynamics experiments with improved temporal resolution.

## PARALLEL SASE AND SEEDED OPERATION

The XUV seeding experiment is supposed to work in parallel to and at the same accelerator settings as for the normal SASE operation at FLASH. Since FLASH uses fixed-gap undulators the electron beam energy will be determined by the SASE-wavelength needed for the experiments with photons. Therefore the gap of the sFLASH undulators has to be changed, so that one always matches the seed wavelength with the electron beam energy. Fig. 5 shows the region in the  $\{\lambda_{\text{sFLASH}}, \lambda_{\text{SASE}}\}$  parameter

space where sFLASH reaches saturation assuming a seed pulse energy of 1 nJ. The black line at the lower side of the gray area represents the limit given by the minimum gap size of the undulator of 9 mm. The horizontal lines indicate some SASE wavelengths typically requested for the photon experiments.

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