# STATUS OF THE XUV SEEDING EXPERIMENT AT FLASH*

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*Abstract*

A seeded free-electron-laser (FEL) operating in the soft X-ray (XUV) spectral range will be installed at the Free-electron- LASer in Hamburg (FLASH). For this purpose, a 40 m long section upstream of the existing SASE undulators will be rebuilt during the shutdown in fall 2009. This includes the injection of the seed beam into a new 10 m variable-gap undulator, the out-coupling of the seeded FEL radiation and all diagnostics for photon- and electron beams. The generation of higher-harmonics (HHG) from near-infrared (NIR) femtosecond laser pulses in rare gas media provides the XUV-seed. After amplification in the undulators the XUV light will be guided toward diagnostic and experimental stations. Besides a proof-of-principle demonstration for direct seeding at short wavelength the purpose of this development is to provide future pump-probe experiments with a more stable FEL source in terms of spectral properties and timing.

## INTRODUCTION

The free-electron-laser FLASH at DESY/Hamburg uses a 140 m long superconducting linac and a 30 m long undulator to deliver XUV pulses of sub-10 fs duration for various experiments [1]. The emitted SASE radiation starts up from noise and consists of a number of uncorrelated modes. This results in a reduced longitudinal coherence and shot-to-shot fluctuations of about 18% (rms) [1]. One way to reduce the pulse energy shot-to-shot fluctuations is to create longer radiation pulses so that more modes contribute to the FEL output. In order to achieve that a 3rd harmonic accelerator modul will be installed during a major maintenance periode end of 2009 [2] [3]. Beside the spectral properties of the FEL another issue is the arrival time jitter of the radiation pulses at the experimental stations. This limits the temporal resolution for pump-probe experiments to a few 100 fs. Various techniques are used for improvement such as arrival time monitors which synchronize external lasers to the electron/FEL beam [4] or feedback systems to stabilize the arrival time of the electron bunches in the undulator [5]. A possibility to increase both, the longitudinal coherence and the temporal resolution for pump-probe experiments, is to seed the FEL directly with XUV pulses created by higher-harmonic generation (HHG) from NIR femtosecond laser pulses [6]. Furthermore this approach ensures a better shot-to-shot intensity stability. In that case the FEL pulse duration will be determined by the HHG seed pulse length of about 20 fs FWHM. The HHG seeding experiment to be installed at FLASH [3] - sFLASH, aims to study the technical feasibility of a seeded FEL at wavelengths below 35 nm.

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## LAYOUT AND STATUS

The general layout of the sFLASH installation is shown in Fig. 1. The two laboratories adjacent to the FLASH tunnel and the sheath tubes which later support the vacuum beam pipes for the photon beams were erected in previous shutdown periods.

### *Laser System, HHG Source and Beamline*

Higher harmonics generation occurs when an intense laser field interacts with an atomic gas target. Therefor short (35 fs FWHM) NIR 800 nm pulses with pulse energies up to 35 mJ at a repetition rate of 10 Hz, provided by a Ti:sapphire laser system, will be focused in a rare gas jet. Depending on different beam focusing schemes, part of the 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 [9] 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 ∼30 nm and ∼13 nm), deflect and focus the beam to guide it onto the electron beam axis. 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 [8]. 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).

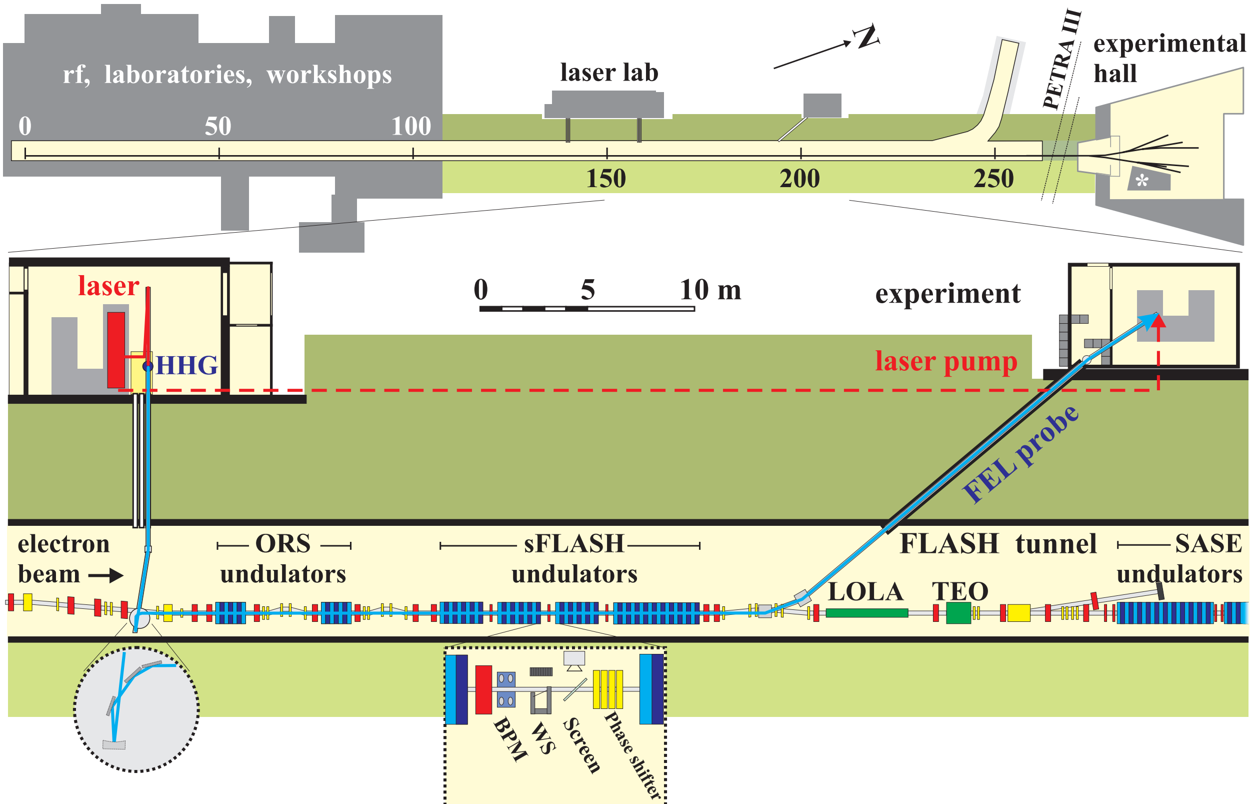


Figure 1: The FLASH facility (top) comprises a 260 m long tunnel housing the linac and undulators of a SASE FEL, followed by an experimental hall. A 40 m long section (bottom) preceding the SASE undulators will be modified to accommodate four additional undulators for sFLASH. Seed pulses from the HHG source in the building adjacent to the FLASH tunnel will be aligned to the electron beam at the last dipole of the accelerator energy collimator (left). At the undulator exit, the electron beam will be displaced while the FEL radiation is sent by mirrors to an experimental hutch. Delayed laser pulses will be sent directly to the hutch for pump-probe applications (dashed line). Also shown are dipole magnets and steerers (yellow), quadrupoles (red) and devices for longitudinal bunch diagnostics (ORS, LOLA and TEO). The dashed bordered boxes show detailed views of the seed incoupling and the undulator intersections.

### *Undulators and Electron Beamline*

The sFLASH undulator section consists of four hybrid variable-gap undulators separated by 0.7 m long intersections. Each accommodates a quadrupole magnet, a phase shifter and a diagnostic unit for photon and electron beam monitoring. For the undulator an existing 4 m long undulator and three new 2 m long undulators designed for the PETRA III synchrotron light source are used [10]. The undulator vacuum chamber is manufactured from extruded aluminum with a vertical aperture of 9 mm and a wall thickness of down to 0.5 mm, similar to the design for the European XFEL [11]. The phase shifter consists of a set of dipole magnets forming a small chicane in order to compensate the shift of the ponderomotive phase in the drift space between the undulators. A diagnostic unit installed at either end of each undulator module allows to determine size and position of the electron and the photon beam. It comprises a beam position monitor, a wire scanner (WS) [12], a silicon screen for optical transition radiation (OTR) measurements and a Ce:YAG fluorescence screen to observe the XUV beam. Electrons scattered by the wire scanner will be detected on scintillator panels from the beam loss monitor (BLM) system. Furthermore micro-channel plates (MCP) are installed near to the wires in order to detect scattered XUV photons. At the exit of the undulator section a magnetic chicane displaces the electron beam vertically to allow the extraction of the FEL beam. The whole sFLASH section will be enclosed by diagnostic sections for longitudinal electron bunch profile measurements, namely an optical-replica synthesizer [13] and a transverse deflecting cavity [14]. The latter is followed by an electro optical beam arrival time monitor (TEO) [15] and an electron spectrometer [3].

### *FEL Beamline*

A mirror chamber with two plane amorphous carbon coated silicon mirrors with grazing incidence at 5° is placed after the last undulator module within a magnetic chicane and can be moved vertically to deflect the XUV radiation into another mirror chamber. Here the beam can be

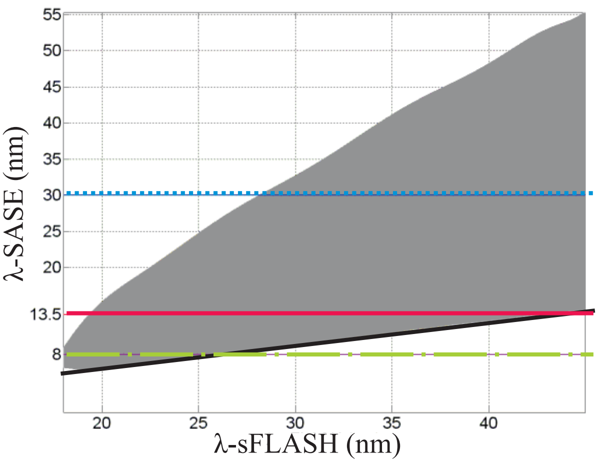


Figure 2: Assuming a seed pulse energy of 1 nJ, the gray area represents working points where saturation of the FEL is expected for a given set of FLASH SASE-wavelengths and sFLASH-wavelength.

deflected either into a diagnostic station or into an experimental hutch. For the diagnostic a beam intensity monitor using a mesh and an MCP similar to the system at FLASH [16] will be installed, together with a spectrometer [17]. Within every beamline, scintillator based beam position monitors are installed to guarantee the position controll and aligning of the FEL beam. In the experimental hutch the XUV pulses can be combined with the naturally synchronized NIR pulses from the HHG laser system. This allows pump-probe experiments with a time resolution in the order of 30 fs.

## PARASITIC OPERATION

One ambition of the sFLASH-project is the parasitic operation of the seeding experiment under SASE conditions at FLASH. Since FLASH uses a fixed-gap undulator the electron beam energy will be determined by the wavelength requested by the users. Therefore the gap of the sFLASH undulators can be changed, such that one always matches the seed wavelength with the given electron beam energy. Fig. 2 shows the region in the $\{\lambda_{sFLASH}, \lambda_{SASE}\}$ parameter space where saturation can be reached under the assumption of 1 nJ seed pulse energy. 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 by the users.

## START-TO-END-SIMULATION

Numerical simulation were performed to estimate the tolerances for the most critical parameters such as electron beam transverse offset, angle and timing jitter with respect to the external seed radiation as well as the energy of the seed pulses [7]. For these studies ideal electron and photon beam conditions were used e.g. constant slice emittance and slice energy spread for the electrons and a perfect Gaussian $TEM_{00}$ mode for the seed beam. To understand the influence of imperfections of such parameters full start-to-end-simulations are going to be done using a six-dimensional phase-space distribution based on simulation results for the 3rd harmonic accelerator module and radiation input files including imperfections caused by the source and the transport beamline.

## CONCLUSION

The hardware preparation for a direct seeding experiment at FLASH in the soft X-ray regime is under way. XUV pulses created by a HHG source from a NIR laser, already installed, will be superimposed with electron bunches from the FLASH accelerator within a new 10 m long variable-gap undulator. From spring 2010 on this gives the possibility to study the robustness of a seeded FEL at wavelength below 35 nm and the feasibility of dynamics experiments with improved temporal resolution.

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## REFERENCES

[1] W. Ackermann et al., Nature Photonics 1 (2007), 336.

[2] K. Flöttmann et al., "Generation of Ultrashort Electron. Bunches by cancellation of non-linear distortions in the longitudinal phase space", TESLA-FEL-2001-06.

[3] S. Schreiber et al., these proceedings (TU5RFP059).

[4] A. Azima et al., Proc. DIPAC'07, Venice, 337.

[5] F. Löhl et al., Proc. EPAC'08, Genoa, 3360.

[6] G. Lambert et al. Nature Physics 4 (2008), 296.

[7] V. Miltchev et al., Proc. FEL'08, Gyeongju, (TUPPH003).

[8] S. Schulz et al., these proceedings (TH6REP091).

[9] C. Winterfeldt et al., Optimal control of high-harmonic generation, Rev. Mod. Phys. 80 (2008), 117.

[10] H. Delsim-Hashemi et al., these proceedings (WE5RFP070)

[11] M. Altarelli et al. (Eds.), The European X-ray Free Electron Laser, Technical Design Report, DESY 2006-097

[12] U. Hahn et al., Nuc. Inst. Meth. A 592 (2008), 189.

[13] J. Bödewadt et al., Proc. FEL'08, Gyeongju, (THBAU04).

[14] M. Röhrs et. al., Proc. PAC'07, Albuquerque, 104.

[15] A. Azima et al., Proc. EPAC'06, Edinburgh, 1049.

[16] L. Bittner et al., Proc. FEL'07, Novosibirsk, 334.

[17] McPerson 248/310G; http://www.mcphersoninc.com