The free-electron laser facility FLASH delivers intense, laser-like radiation in the extreme ultraviolet (XUV) and soft X-ray spectral range down to 4.12 nm to five user beamlines [1]. In the current SASE operation mode the spectral structure of the FEL pulses fluctuates from shot-to-shot due to the stochastic nature of the start-up process from noise. One solution to overcome these statistical fluctuations is to directly seed the FEL amplifier with an external laser. Another consequence of the direct laser seeding is that the amplified FEL pulses will be intrinsically synchronized with the external laser pulses. In that case, the temporal resolution for pump-probe experiments should be limited only by the individual pulse lengths.

In 2010 an experiment (sFLASH) to test the feasibility of external laser seeding below 40 nm was installed at FLASH [2]. The external seed radiation is generated in a high-harmonic generation (HHG) source driven by a conventional near-infrared (NIR) Ti:Sapphire laser system. All hardware components for the experiment were commissioned in 2010 [3]. The procedures to establish the laser-electron overlap and the data acquisition tools were ready for the first seeding shifts in March and April of 2011. Three shift blocks of 24 hours of consecutive beam time were allocated. About one third to one half of each shift block was used to prepare the machine for seeded operation, containing emittance measurements, dispersion correction, and bunch compression control. The transverse deflecting structure and the electron spectrometer [4] were used, to measure and optimize the longitudinal phase space distribution of the electron bunches. About four to six hours of beam time were needed to establish the spectral, transverse and longitudinal laser-electron overlap (see Fig. 1). The rest of the time was used to perform timing scans while acquiring FEL spectra. About one million FEL spectra were recorded during all shift blocks. A dedicated scan procedure was used to find a first signal for seeding during the scans, but no evidence for seeding could be seen. Also the post analysis of the FEL spectra could not give any evidence for established seeding. The most probable reason for this is the relatively low pulse energy of the 21st harmonic (38.6 nm) of the HHG source of about 2 nJ at the source and a bad coupling efficiency between the seed radiation and the electron bunches at the undulator caused by a large XUV beam. One decided to improve the laser setup for the HHG source and to implement more diagnostics in the injection beamline, before making a new attempt for seeding. The changes were installed during the shutdown period in autumn 2011. A new XUV photo diode in front of the undulator allows now to measure the absolute pulse energy of the seed laser at the interaction point with the electron beam. A micro-channel plate (MCP) was installed close to the last injection mirror, allowing to measure the XUV pulse energy on-line by detecting photoelectrons emitted from the mirror surface. With this, a direct correlation of the seed pulse energy with the FEL pulse energy will be possible. The drive laser system for the HHG source was modified. A new Ti:Sapphire oscillator was installed operating at a repetition rate of 108 MHz, which is better suited for the synchronization with the master oscillator of FLASH. The amplifier laser system was maintained and modified. After that the pulse energy stability could be measured to be below 1.5 % (rms). An in-vacuum reflective grating compressor was installed replacing a two-stage compression scheme. The new on-stage compression scheme allows to get a factor of
two more NIR pulse energy of about 20 mJ into the HHG target. In addition, it allows a better controllability of the NIR beam parameters at the HHG target. The new setup allows to generate about seven times more pulse energy at the 21st harmonic and an energy stability better than 5% (rms). The improved diagnostic setup for the HHG source could be used to measure the transverse beam quality of the HHG beam. First measurements show an $M^2$ between 5 and 7 for the 21st harmonic. The beam size at the undulator entrance was measured to be 70 to 120 $\mu$m (rms) (see Fig. 2). With the substantially improved current setup we reach the original project specifications giving us the opportunity observe FLASH seeding in the near future.

![Figure 1](image1.png)

Figure 1: Results of the six-dimensional overlap measurements. Superimposed beam profiles of XUV seed beam and electron beam (black circular mask) in front (a) and after (b) of the first undulator module. (c) shows a measurement of the arrival time of electron and photons, here seperated by about 2 ps. (d) shows an average SASE spectrum of the FEL (blue solid) and a spectrum of the HHG source (red dashed), both measured at the same spectrometer.

![Figure 2](image2.png)

Figure 2: Performance of the new HHG source setup. Left: Pulse energy of the 21st harmonic measured with a calibrated CCD. The maximum value of the old setup is indicated. Right: Measured beam size along the wide and narrow axis of the beam profile of the XUV beam at the entrance of the undulator.

References