FLASH2 BEAMLINE AND PHOTON DIAGNOSTICS CONCEPTS

Elke Plönjes#, Bart Faatz, Josef Feldhaus, Marion Kuhlmann, Kai I. Tiedtke, Rolf Treusch
Deutsches Elektronen-Synchrotron, Hamburg, Germany

Abstract

The FLASH II project will upgrade the soft X-ray free electron laser FLASH at DESY into a multi-beamline FEL user facility with the addition of a second undulator line FLASH2 in an additional tunnel. The FLASH linear accelerator will drive both undulator lines and FLASH2 will be equipped with variable-gap undulators to be able to deliver two largely independent wavelengths to user endstations at FLASH1 and FLASH2 simultaneously. A new experimental hall will offer space for up to seven user endstations, some of which will be installed permanently. The beamline system will be set up to cover a wide wavelength range and it will include online photon diagnostics for machine operators and users. Up to three beamlines will be capable of transporting the 5th harmonic at 0.8 nm and a fundamental in the water window while others will cover the longer wavelengths of 6 - 40 nm and beyond. Civil construction and installations of FLASH2 are on-going and first beam is expected for early 2014.

INTRODUCTION

FLASH, the free electron laser user facility for the XUV and soft X-ray range at DESY, has delivered high brilliance radiation for photon experiments since 2005 [1-3]. The FLASH II project will upgrade FLASH into a multi-user facility. The new tunnel and experimental hall have space for two new undulator lines, FLASH2 and FLASH3, with respective beamlines. Within the FLASH II project the first new undulator line FLASH2 is realized with initially one photon beamline.

The FLASH linac drives both the FLASH1 fixed gap undulator line and the new FLASH2 variable gap undulator line as shown in Figure 1. Only moderate modifications in the linear accelerator section are needed, such as a second injector laser, and the addition of an electron kicker to kick the electron bunches into FLASH2. Due to the simultaneous use of one accelerator the electron beam energy is the same for both beamlines. The FLASH2 undulators have gaps variable from 9 to 20 mm to allow for a significant tuning range for FLASH2 at the various wavelength of FLASH1 [4,7]. Thus, FLASH will operate two FEL beams in parallel and double the user beamtime, which is presently overbooked by about a factor of four. Details of FLASH, its parameters, and the necessary modifications of the machine for the FLASH II project are found in [5-8]. Table 1 lists the electron- and photon-beam parameters of FLASH2, including possible upgrades.

The experimental Hall of FLASH2 (and FLASH3) is a civil construction of 60.5 by 33 meters. It will house a 14 m long main photon diagnostics section for users, up to seven FLASH2 and in the future also several FLASH3 beamlines [4]. Similar to FLASH1, a THz beamline [9] and an optical laser system [10] for pump-and-probe experiments complete the user facility. The wide wavelength range, which is covered by FLASH2, poses significant challenges for the optics layout.

PHOTON DIAGNOSTICS

Tunnel

In the new FLASH II tunnel, a set of photon diagnostics serves mainly the machine for optimization of the photon beam. It is positioned directly behind the electron beam dump bending magnet.

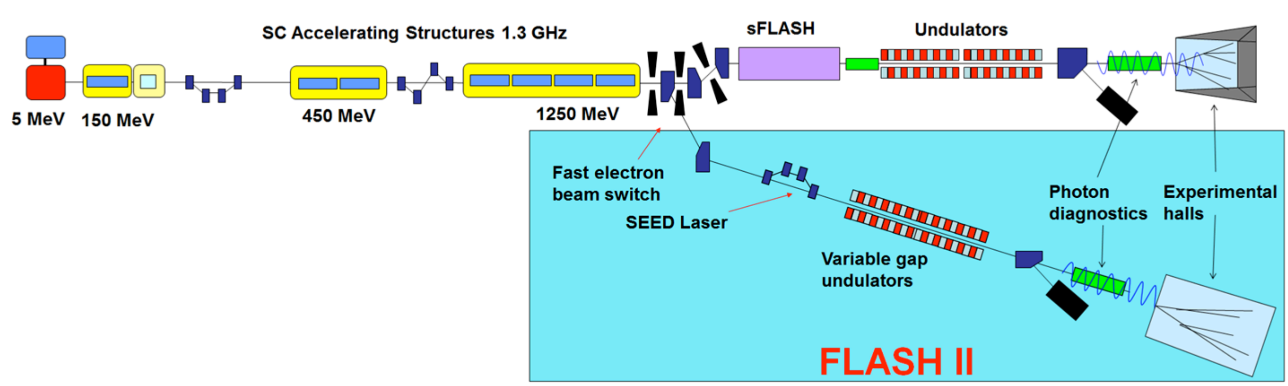

Figure 1: Layout of the FLASH facility with two undulator lines FLASH1 and FLASH2 (not to scale).

#elke.ploenjes@desy.de

ISBN 978-3-95450-126-7

Well established tools, which are described in detail in [1, 4, 11], will be available to operators for machine setup and tuning. The tunnel photon diagnostics are designed keeping in mind their position close to the source point, 10 – 25 m, where the photon beam is very small and intense. These diagnostics include an alignment laser, apertures, crystal fluorescence screens, a gas monitor detector (GMD) [12], an online photoionization spectrometer (OPIS) [11], and an MCP tool [13]. Many of these photon diagnostic tools rely on controlled gas pressures and they are therefore separated by numerous differential pumping stages. The machine photon diagnostics end with a retractable copper absorber under a 6° incidence angle, which should at this position withstand up to 800 pulses at 1 MHz for the entire anticipated parameter range. This allows for machine operation while the beamlines are not in use.

The necessary passage of the beamline through the PETRA III tunnel will be occupied with a gas attenuator of approximately 14 m length. A choice of Xe, N_2, Kr, or Ar provide smooth and edge-less attenuation curves for the entire wavelength range. Operation up to 0.5 mbar is required to achieve a reasonable attenuation of up to 10^{-3} for the wavelength range of FLASH2. This places high demands on the differential pumping systems.

Experimental Hall

At FLASH, each individual photon pulse varies in its parameters due to the stochastic SASE generation process. Therefore, a second photon diagnostics section is placed at the entrance of the experimental hall, which delivers a complete set of photon beam parameters - intensity, position, wavelength and in the future also pulse length - non-destructively on a shot-to-shot basis for user experiments[1, 4, 11]. Also equipment, which cannot withstand a beam power density close to the source, is placed here.

These photon diagnostics will serve mainly the users and contain again an alignment laser, two sets of apertures and fluorescence screens about 5 m apart, a GMD with two beam position monitors and an OPIS wavelength spectrometer. Space it reserved in this section for a pulse length diagnostic. Different techniques for online pulse length detection are currently under investigation [14-16]. However, even though significant success has been achieved for these techniques, a photon pulse length monitor for the full parameter range of FLASH and in a parasitic manner is still a challenge. The section is closed off again with a 6° copper absorber 46 m behind the source. Finally, a fast shutter and set of filter units [1] for solid filters round off the main photon diagnostics in front of the separation of the beamlines.

These photon diagnostics for users are fully independent of the machine photon diagnostics in the tunnel and give them the option to set up alignment lasers, apertures, filters etc. according to their requirements. At the same time, this second photon diagnostics set gives a redundancy in the systems and allows more precise measurements due to a lower electromagnetic noise environment than in the FLASH 2 tunnel. This is of particular advantage for the GMD system and the OPIS spectrometer, which can suffer significantly in their accuracy from such noise.

Finally, special photon diagnostic tools and beamline components, such as split-and-delay-units, will be included into individual beamlines and at the user end stations. Filters, apertures, slits, screens, additional alignment lasers, a portable GMD intensity monitor [12], a compact grating spectrometer [17], and several wave front measurement systems [18-20] have proven to be useful tools at the experiments of FLASH and will be available for FLASH2.

BEAMLINES

The photon beam distribution system and the photon diagnostics are designed to cover a very wide wavelength range of 0.8 - 40 nm with 6σ of the beam footprint in both directions and to even higher wavelengths up to 80 nm with a lower geometrical beamline acceptance. This large wavelength range for the beamlines as well as the photon diagnostics permits transport of higher harmonics and already incorporates the option for future energy up-grades of the FLASH accelerator beyond 1.25 GeV. It covers the needs voiced by the different FLASH user communities.

Table 1: FLASH2 Electron- and Photon-beam Parameters

FLASH2 Parameters			
e-beam		photon parameters	
energy	0.5-1.25 GeV	fundamental wavelengths	40 – 4 nm
energy upgrade option	1.6 GeV	(with upgrade)	40 - 2.5 nm
peak current	2.5 kA	transported wavelengths	> 0.8 nm
bunch charge	0.02-1 nC	pulse duration (fwhm)	10-500 fs
energy spread	0.5 MeV	spectral width (fwhm)	0.5-2 %
bunch spacing	1-25 μs	average single pulse energy	1-500 μJ
repetition rate	10 Hz	peak power	1-5 GW
divergence at 40 nm (σ)	75 μrad	peak brilliance	10^{28}-10^{31} *
divergence at 16 nm (σ)	38 μrad		
divergence at 6 nm (σ)	17 μrad		
divergence at 2.5nm (σ)	10 μrad		* photons / (s mrad^2 mm^2 0.1% bw)

ISBN 978-3-95450-126-7

Tunnel

The first two mirrors of the photon beam distribution system are positioned already in the FLASH2 tunnel. This is a major difference of the optical concept of FLASH2 to the FLASH1 optical distribution system. These mirrors are part of the radiation safety concept by separating the FEL beam from the trajectory of the e-beam Bremsstrahlung. Thus, the entire experimental hall will be freely accessible without radiation safety restrictions. At the same time, the mirror pair will be used to compensate for angle and position variations of the photon beam. Thus, a stable photon beam position and pointing at the entrance of the experimental hall will be achieved. For this purpose the mirror chambers are equipped with two translations perpendicular to the beam as well as angle movements of rotation and roll.

The two Si mirrors are placed 19 and 20 m behind the photon source. To transport the full wavelength range of FLASH2 a 1° incidence angle and three different coatings, diamond like carbon, nickel and B_4C, are required. Even at this position close to the source, a mirror length of 800 mm is necessary to transport the entire wavelength range with 6σ for the calculated divergences [4].

Experimental Hall

The development of the beamlines will proceed in different phases in the next years. A very preliminary layout of FLASH2 with up to 7 beamlines, which is currently under discussion, is shown in figure 2. The focal points of the beamlines in the experimental areas will be at distances between 76 m and 96 m from the photon source.

and a reasonable separation of the endstations have to be taken into account.

These considerations have led to a beamline concept with three beamlines, FL23 (FLASH2 beamline 3), FL24, and FL25, incorporating only mirrors under 1° grazing incidence to cover the short wavelength end. They will operate from 16 nm – 0.8 nm with 6σ acceptance. FL24 will cover the full spectral range since it does not have any optics far from the source in the experimental hall except for optional focusing optics. Also, for FL24 a split-and-delay unit in the design of H. Zacharias et al. [21] with 1.8° incident angle optics for a maximum delay of 24 ps is proposed. The beamlines FL21, 22, 26 and 27 cover the original FLASH design parameters, i.e. a wavelength regime of 6 – 40 nm with 6σ beam size acceptance and up to 80 nm with 3σ. With the restriction to wavelengths > 6 nm, a beamline separation with only carbon coated, short, plane mirrors under 4° incident angle will be possible.

With FLASH1 and 2 in operation, FLASH supports a significantly increased number of beamlines. Therefore, in the future, a combination of long-term/permanent user endstations for widely used techniques will be combined with the roll-on roll-off of specialized user experimental chambers only for the beamtimes as it was previously exclusively practiced at FLASH. Some of the new beamlines will be specifically set up for the permanent end stations. Wherever it will be possible, the beamline end will offer both, a focused and an unfocused branch for users who wish to bring their own focusing systems.

Since a very high number of user experiments use pump-and-probe techniques, several sources will be available at FLASH2 for this purpose, split-and-delay units (see

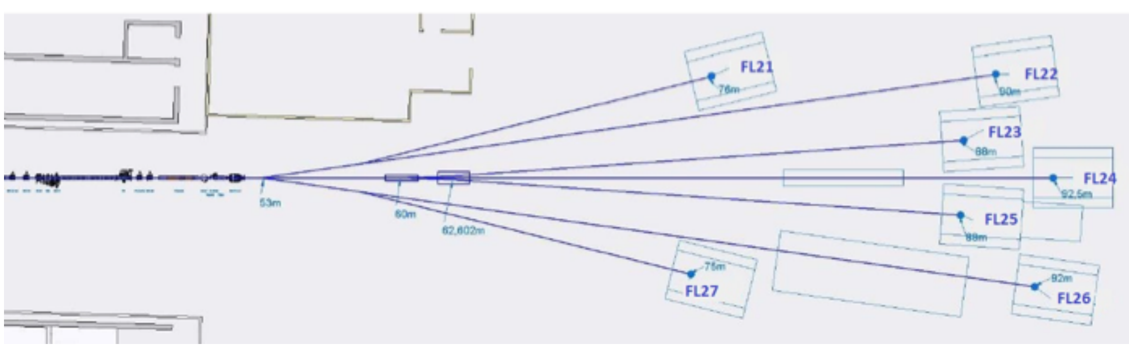

Figure 2: A preliminary FLASH2 beamline distribution with a 14 m main photon diagnostics line and 7 possible beamlines.

The short wavelength end of the FLASH2 range as well as transporting high harmonics require very grazing incidence angles of 1° for the optics not only for reflectivity reasons, but also due to the expected pulse powers and bunch train patterns of FLASH. For the longer wavelengths the divergences are significantly larger and they cannot be transported with 1° mirrors of reasonable sizes of up to 1 m with a good beamline acceptance to the endstations [4]. Also, the overall layout

above), a tunable optical laser and a THz undulator source. The new optical laser is an optical parametric chirped-pulse amplification laser system (OPCPA) [4, 22, 23] with wavelengths tuneable from 650 - 1100 nm. For the FLASH2 endstations, a versatile interconnection system from the beamline to the user experiments is envisaged, which will contain differential pumping and a fixed in-coupling for a collinear pump-probe setup. A

ISBN 978-3-95450-126-7

THz undulator and beamline, similar to FLASH1 [9], are included in the FLASH2 design. This will open the opportunity for XUV-THz pump-probe experiments for at least one endstation of FLASH2, FL25.

SUMMARY

The FLASH II project is a major extension, which will upgrade the soft X-ray free electron laser FLASH at DESY into a multi-beamline FEL user facility. The second undulator line FLASH2 will be equipped with variable-gap undulators to be able to deliver two largely independent wavelengths to user endstations at FLASH1 and FLASH2 simultaneously. Civil construction of the new buildings has started in autumn 2011 and will continue in several steps until the beginning of 2014. Mounting of the electron beamline has started in spring 2013, and commissioning with beam is scheduled to start in early 2014. A new experimental hall will offer space for up to seven user endstations, some of which will be installed permanently. The beamline system and a complete set of photon diagnostics will be set up to cover a wide wavelength range with up to three beamlines capable of delivering the 5th harmonic at 0.8 nm and a fundamental in the water window while others will cover the longer wavelengths of 6 – 40 nm and beyond.

ACKNOWLEDGEMENTS

The authors would like to thank the FLASH team at DESY and all collaboration partners for their contributions.

REFERENCES

[1] K. Tiedtke et al., " The soft X-ray free-electron laser FLASH at DESY: beamlines, diagnostics, and end stations ", New J. Phys. 11, 023029 (2009).

[2] W. Ackermann et al., "Operation of a Free-electron Laser from the Extreme Ultraviolet to the Water Window." Nat. Phot. 1, 336 (2007).

[3] S. Schreiber et al. "Status of the FLASH facility", Proc. IPAC 2012, New Orleans, USA (2012).

[4] M. Kuhlmann, E. Plönjes, Proceedings of SPIE Optics + Optoelectronics 2013, Prague, Czech Republic (2013)

[5] B. Faatz et al., "Flash II: Perspectives and Challenges", Nucl. Instr. Meth. A 635, S2-S5 (2011).

[6] K. Honkavaara " Status of FLASH II Project" Proc. FEL 2012, Nara, Japan, (2012)

[7] B. Faatz et al., "FLASH II: A Project update", Proc. IPAC 2012, New Orleans, USA (2012).

[8] V. Ayvazyan et al., "First operation of a Free-Electron Laser generating GW power radiation at 32 nm wavelength", Eur. Phys. J. D **37**, 297-303 (2006)

[9] M. Gensch et al., "New infrared undulator beamline at FLASH", Infrared Phys. Technol. 51, 423-425 (2008).

[10] H Redlin et al., Nucl. Instr. Meth. A 635, S88-S93 (2012)

[11] K. Tiedtke et al., Proc. FEL2013, New York, USA (2013)

[12] K. Tiedtke et al., "Gas detectors for x-ray lasers", J. Appl. Phys. 103, 094511 (2008).

[13] L. Bittner et al., "MCP-based Photon Detector with Extended Wavelength Range for FLASH", Proc. FEL2007, Novosibirsk, Russia (2007).

[14] I. Grguras et al., "Ultrafast X-ray pulse characterization at free-electron lasers", Nat. Phot. 6, 852-857, (2012).

[15] Th. Maltezopoulos et al., "Single-shot timing measurement of extreme-ultraviolet free-electron laser pulses", New J. Phys. 10 (2008) , 033026

[16] M. Krikunova et al., "Ultrafast photo- fragmentation dynamics of molecular iodine driven with timed XUV and near-infrared light pulses", J. Chem. Phys. 134, 024313 (2011).

[17] F. Frassetto et al., "Compact spectrometer for photon diagnostics of the extreme-ultraviolet free-electron-laser radiation" Nucl. Instr. and Meth. A 635, S94-S98 (2010).

[18] B. Flöter et al., "EUV Hartmann sensor for wavefront measurements at the Free-electron Laser in Hamburg", New J. of Phys. 12, 083015 (2010).

[19] B. Flöter et al., "Beam parameters of FLASH beamline BL1 from Hartmann wavefront measurements", Nucl. Instr. And Meth. A 635, 108-112 (2011).

[20] B. Schäfer et al., "Hartmann-Shack wave front measurements for real time determination of laser beam propagation parameters", Rev. Sci. Instrum. 77, 053103 (2006).

[21] M. Wöstmann, et al., "The XUV split-and-delay unit at beamline BL2 at FLASH", J. Phys. B: At. Mol. Opt. Phys. **46**, Special Issue: Frontiers of FEL Science, 164005 (2013).

[22] F. Tavella et al., "Fiber-amplifier pumped high average power few-cycle pulse non-collinear OPCPA", Opt. Express 18, 4689-4694 (2010).

[23] D. Herrmann et al., "Investigation of two-beam-pumped noncollinear optical parametric chirped-pulse amplification for the generation of few-cycle light pulses", Opt. Express 18, 4170 (2010).

ISBN 978-3-95450-126-7