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FLASH2020+ PLANS FOR A NEW COHERENT SOURCE AT DESY*

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Abstract

With FLASH2020+, a major upgrade of the FLASH facility has started to meet the new requirements of the growing soft X-ray user community. The design of the FEL beamlines aims at photon properties suitable to the needs of future user experiments with high repetition rate XUV and soft X-ray radiation. By the end of the project, both existing FEL lines at FLASH will be equipped with fully tunable undulators capable of delivering photon pulses with variable polarization. The use of external seeding at 1 MHz in burst mode is part of the design of the new FLASH1 beamline, while FLASH2 will exploit novel lasing concepts based on different undulator configurations. The new FLASH2020+ utilise electron beam energies up to 1.35 GeV which will extend the accessible wavelength range to the oxygen K-edge with variable polarization. This will be complemented by new laser sources for pump and probe experiments and new experimental stations.

FLASH FEL USER FACILITY

Since the first operations of the FLASH FEL for users started more than 15 years ago [1, 2] the facility has experienced a series of upgrades in order to extend its capabilities and to fulfil the increasing demands of the growing X-ray user community. The last major upgrade involved the implementation of a second FEL line [3] allowing to serve two experiments simultaneously with parameters as reported in Table 1 and in [4].

Table 1: Current FLASH FEL Parameters

	FLASH1	FLASH2
Wavelength (nm)	4.2 – 51	4 – 90
Photon energy (eV)	295 – 24	310 - 14
Spectral width (FWHM)	0.7 – 2 %	0.5 – 2 %
Peak power (GW	1 – 5	1 – 5
Pulse length (fs)	(5) 30 – 200	(5) 30 – 200
Pulses per seconc	10 - 5000	10 - 5000
Polarization	Horizontal	Horizontal

Currently both FELs, relying on the self-amplified spontaneous emission mode, can provide high peak power pulses with pulse lengths ranging from tens to hundreds of fs depending on the electron beam compression. Special operation modes have also been implemented to allow few fs pulses in single spike SASE mode [5] that has opened new possibilities in terms of high resolution time-resolved experiments [6].

FLASH2020+ UPGRADE

Following an extensive discussion with the FLASH user community, a conceptual design report for a major upgrade of the facility has been recently published [7] starting the FLASH2020+ project. New and planned upgrades occurring at different parts of the machine (Fig. 1) are now included in the project that has started in 2020 with a multi-fold goal: consolidating the linac capabilities, improving the parallel use of the two FEL lines, expanding the photon parameters, increasing the experimental capabilities.

Linac Upgrades

Plans for the upgrade of the linac includes:

- New photocathode lasers.
- Replacing two accelerating modules.
- New electron beam compression scheme.
- A laser heater.
- Additional transverse deflecting cavity

The FLASH photocathode laser system has been successfully operated for more than 15 years and with some upgrades has allowed to accommodate the increasing demands given by the need to operate two FEL lines and a THz source [8]. For a further upgrade of the system, few years ago an R&D work has started aiming at designing a new laser system for the FLASH photocathode [9]. The new laser is under construction and will be installed in the accelerator in 2022.

Increasing the linac energy to 1.35 GeV will be possible by replacing two of the old accelerating modules. Thanks to the gained experience over the past years superconducting modules with an average energy gain of more than 27 MeV/m are nowadays available [10]. By replacing the two old modules downstream the first bunch compressor the energy of the beam in the second bunch compressor will be increased from 450MeV to 550MeV allowing to reach a final energy of 1.35GeV.

The design of a new compression scheme relying on two C-shape chicanes and dedicated matching sections will

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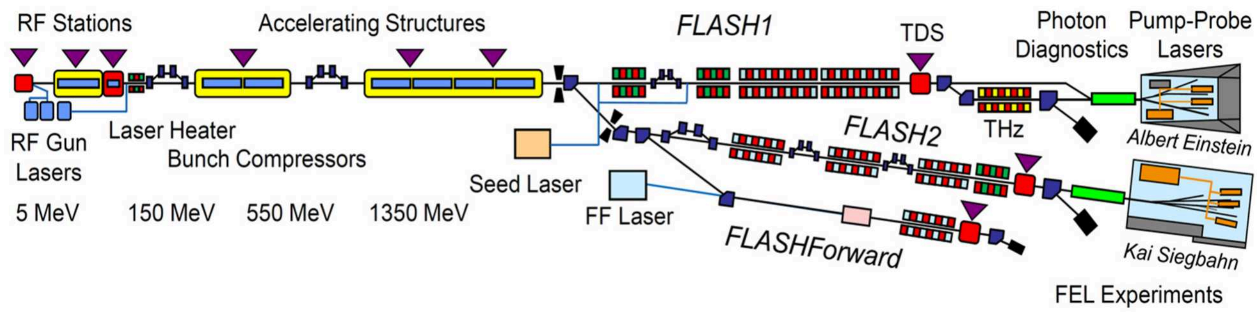

Figure 1: Schematic view of the FLASH facility after FLASH2020+ upgrade (not to scale). The total length is 320 m.

allow to improve the longitudinal and transverse dynamic of the electron beam [11]. Moreover, a final compressor is added in front of the SASE FEL undulators allowing independent tuning of the electron beam peak current and further optimization of the FEL properties.

A Laser Heater system has been designed for FLASH [12] to allow a fine control of the beam energy spread and suppression of the microbunching instabilities. The new laser heater section will be installed in the injector directly upstream of the first bunch compressor (see Fig. 1) during the shutdown 2022.

Transverse Deflecting Cavities have been demonstrated to be powerful tools not only for the fine tuning of the electron beam phase space [13] but also for an online measurement of the FEL pulse length [14]. A new PolariX system has been recently installed downstream the radiators of FLASH2 and will allow measuring the electron beam longitudinal phase space with 5 fs resolution.

Independent FELs

Since the installation of the second FEL line FLASH2 [3], FLASH has been capable of operating two FEL in parallel feeding two user experiments simultaneously. However, this option is currently limited by the need to adjust the common electron beam energy due to the use of fix gap undulators in FLASH1. The installation of variable gap undulators in FLASH1 will make the two FELs completely independent allowing a more intense use of the parallel operation with the benefit of increasing the overall number of user experiments per year.

New Photon Parameters at FLASH

With the upgrade plans now joined in FLASH2020+ new photon properties will be accessible to the FLASH users, mainly: broader tuning rage, polarization control, higher spectral stability, higher coherence.

An Afterburner Undulator installed downstream the main SASE undulator of FLASH2 will allow to extend the tuning range down to 1.4 nm [15]. Thanks to the use on APPLE-III design, circular dichroism experiments will become possible in an interesting spectral range. With a proper setting of the upstream SASE undulator, about 1 µJ per pulse are expected down to the Oxygen–K edge from the afterburner undulator.

APPLE-III undulators will be used for the new FLASH1 allowing both wavelength tuning and polarization control.

External seeding will be used for the new FLASH1 FEL line allowing generating highly coherent and stable pulses. To extend the tuning range of the new seeded FEL line down to 4 nm an Echo Enabled Harmonic Generation scheme setup will be employed [16]. A major goal of the new seeded source is to allow taking full advantage of the repetition rate of the FLASH accelerator (10Hz in burst mode with 500 pulses at 1MHz repetition rate per burst). This requires major efforts in the design of a suitable laser capable of providing the stringent parameters required for seeding at full repetition rate [17].

Powerful THz Radiation [18] will be generated from a dedicated undulator downstream the main FEL undulator and available for pump and probe experiments. By using a double bunch injection in the accelerator [19] two naturally synchronized pulses (THz and soft X-ray) can be generated opening unique capabilities for pump and probe.

Advanced FEL Schemes such as reverse tapering [20] and harmonic lasing [21] together with new undulators on FLASH2 will allow to further extend the tuning range to shortest wavelength and produce few fs short pulses.

New Experimental Capabilities

Within the FLASH2020+ project it is planned to design experimental stations that could take full advantage of the new photon properties of FLASH. Moreover, new flexible pump and probe systems are planned to extend the capabilities for time resolved experiments.

The Beamline FL23 has been designed for making the best use of the new possibilities from FLASH2 short pulses. Thanks to a pulse length compensating monochromator the beamline is designed for time-resolved experiments in the 20 nm to 4 nm spectral range.

The FL11 Beamline is under design with the goal of allowing optimal use of the soft-Xray pulses from the seeded FEL with the powerful THz pulses for unique pump and probe capabilities.

Flexible Pump and Probe systems are of major importance to allow time-resolved experiments. To support the needs coming from different user communities a flexible laser system is required capable of providing

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various options ranging from short pulses in the UV to wavelength tunable pulses in the MIR.

PROJECT TIMELINE

The project is organized in four different phases (Fig 2). Those upgrades already planned and included in the FLASH2020+ project are grouped in Phase 0. In Phase 1 and Phase1+ are present all other major upgrades to the facility to be concluded by the end of 2024. The final upgrade of the FLASH2 line is part of the Phase 2 currently focused on the studies needed to identify the best option to accommodate the requests from users for short wavelength and short pulses.

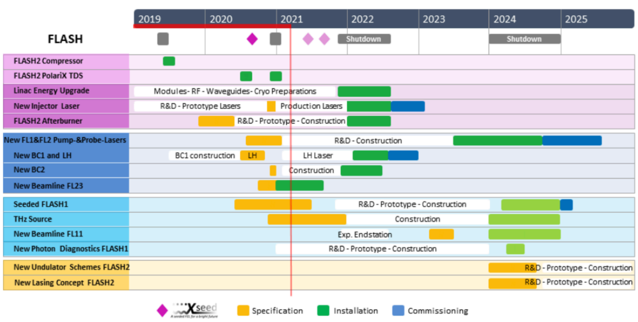

Figure 2: Timeline of the FLASH2020+ project. The different colors of the rows depict the project's phases.

To complete the various upgrades two long shutdowns of the facility are required. During the first 9-month shutdown starting in November 2021 the accelerator upgrade will be completed together with all other plans part of Phase 0. In 2022, FLASH operations will resume with an improved electron beam and will serve users for about 1 year and half before the second long shutdown. The shutdown in 2024 will allow the full reconstruction of the FLASH1 FEL together with the photon beamlines, new photon diagnostic, the installation of new seed and pump and probe lasers.

Beginning of 2025 FLASH will start operation with the new seeded FEL line on FLASH1 capable of generating highly coherent and reproducible pulses with much higher repetition rate than currently available at other facilities. After the required commissioning period of the new seeded FLASH1, FLASH will be capable of supporting parallel experiment with two complementary sources combined with flexible pump and probe schemes.

CONCLUSION

With the FLASH2020+ project, FLASH facility has started an upgrade program that would significantly extend the capabilities of the facility and would allow to support the growing needs of scientists in the soft X-ray spectral range.

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