FLASH User Operations Newsletter, March 2019

Dear colleagues,

in order to support and inspire you when writing a proposal for FLASH, we put together this fourth issue of our newsletter. With this, we want to keep you updated on our recent activities and developments at the FLASH user facility. References and contact names for the corresponding in-depth information on new instrumentation and features are added to the brief summaries given here.

We would be happy to provide you with further specific details on request and are looking forward to receive your experiment proposal.

With best regards,

Wilfried Wurth and *Rolf Treusch*

FLASH2020+ Update

Our plans for the future of FLASH, FLASH2020+, were presented to the users in a satellite workshop to the DESY Photon Science users meeting on January 22nd. The feedback from our users was very positive. We are now in the process of finalizing the Conceptual Design Report for FLASH2020+. The goal is to have the CDR ready by end of March. It will then be presented to our advisory bodies in the second quarter of the year. After final approval of the plans by the DESY directorate as well as the Science Council and the Foundation Council we will work on a Technical Design Report. If everything runs as planned we expect the implementation phase to start 2021 with the upgrade of the FLASH1 line to an externally seeded high repetition rate FEL with tunable undulators.

THz doubler at FLASH: double pulses for more flexible pump-probe experiments

Together with the experts from the machine side, the FLASH THz team is presently thoroughly investigating the so called 'THz doubler' scheme [1], where two electron bunches are fed into the accelerator, separated by 21.5 ns only. With this scheme, we want to tackle the issue of the about 7 m longer optical path of the THz compared to the XUV beamline, since the current solution to "artificially delay" the XUV pulse via a back-reflecting multilayer (ML) mirror with a focal length of ~3.5 m has some drawbacks.

The THz doubler scheme is sketched in Figure 1: In order to optimize conditions for a typical THz pump - XUV probe experiment, we suppress XUV lasing of the 1st bunch to 1 % or less of that of the 2nd – presently for about 50 % of the shots – by appropriate machine settings. Though this approach now uses two separate pulses for the THz and XUV generation, the relative timing of the two pulses is still very stable. Synchronization of the THz-doubler radiation pulses is measured to be around 20 fs (rms), and a solution for monitoring arrival times to achieve an even higher temporal resolution has been developed [1,2]. THz pulse energies produced with the doubler concept are currently in the 10 µJ range. Since exploiting the full potential of this scheme also requires precise intensity monitoring of the nanosecond spaced XUV pulses, the GMDs at FLASH1 will soon be upgraded to new, faster electronics hardware.

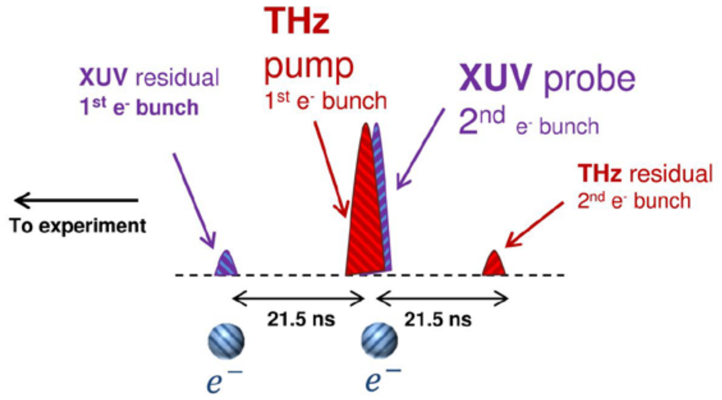

Figure 1: THz doubler timing scheme: 1st electron bunch generates "residual" XUV pulse and THz pump pulse, while 2nd generates XUV probe (temporally overlapped at the experiment with THz pump) and "residual" THz pulse. Residual pulses are not used in pump-probe experiment.

In summary, the THz doubler scheme is almost mature meanwhile and will soon be suited to replace the ML mirror approach at the experimental end-station. This will allow to go for a significantly better and ultimately flexible focusing scheme (a KB focusing mirror system is in preparation). In addition, one also gets rid of the wavelength limitations of the former ML mirror, thus wavelength changes on demand (e.g. for scans across a resonance) are no longer hindered. One can hence fully profit from the tunable gap XUV undulators which are in preparation for FLASH1.

We are currently looking forward to collaborative "friendly user" experiments to demonstrate the full potential of the THz doubler method.

[1] E. Zapolnova et al., *THz pulse doubler at FLASH: double pulses for pump-probe experiments at X-ray FELs*, J. Synchrotron Rad. 25, 39-43 (2018); https://doi.org/10.1107/S1600577517015442

[2] R. Pan et al., *Photon diagnostics at the FLASH THz beamline*, J. Synchrotron Rad., accepted (March 2018)

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KALYPSO: a fast line detector applied for MHz readout of FEL single pulse spectra

(Update to *Taking spectra "on the fly"*, FLASH Newsletter 9/2017)

A novel line detector named KALYPSO (KArlsruhe Linear arraY detector for MHz rePetition-rate SpectrOscopy) in version 2.1 [3] was implemented at the variable line spacing (VLS) online spectrometer [4] at FLASH1 for sampling all the spectra of individual pulses in a train [5]. The KALYPSO detector has been developed in a collaboration between the Karlsruhe

Institute of Technology (KIT), the Paul-Scherrer-Institute (PSI) in Switzerland and DESY. It was integrated into the data acquisition (DAQ) system at FLASH and is triggered by an MTCA trigger signal, such that it allows to record the spectra of several hundred FEL pulses in a pulse train at 1 MHz readout rate for a full line/spectrum. The image of a sequence of spectra, one below the other (Figure 2) is available on demand in the FLASH control room. It can be used as a very efficient tool for the FLASH operators during machine tuning to keep all individual FEL pulses in a train within a narrow wavelength band close to the intrinsic ~1 % bandwidth of an individual pulse.

On the other hand, this intra-train pulse-resolved spectral diagnostics also allows to precisely do just the opposite, namely to increase and control the available FEL bandwidth by chirping the electron beam energy over the pulse train (Figure 2, lower right). As was recently shown in a user experiment, monochromator scans for, e.g., X-ray absorption spectroscopy (XAS) are substantially simplified that way, working with about twice the intrinsic SASE bandwidth.

As was demonstrated before already, the information about the spectral shape of individual pulses can also be applied in user experiments to improve the spectral resolution [6].

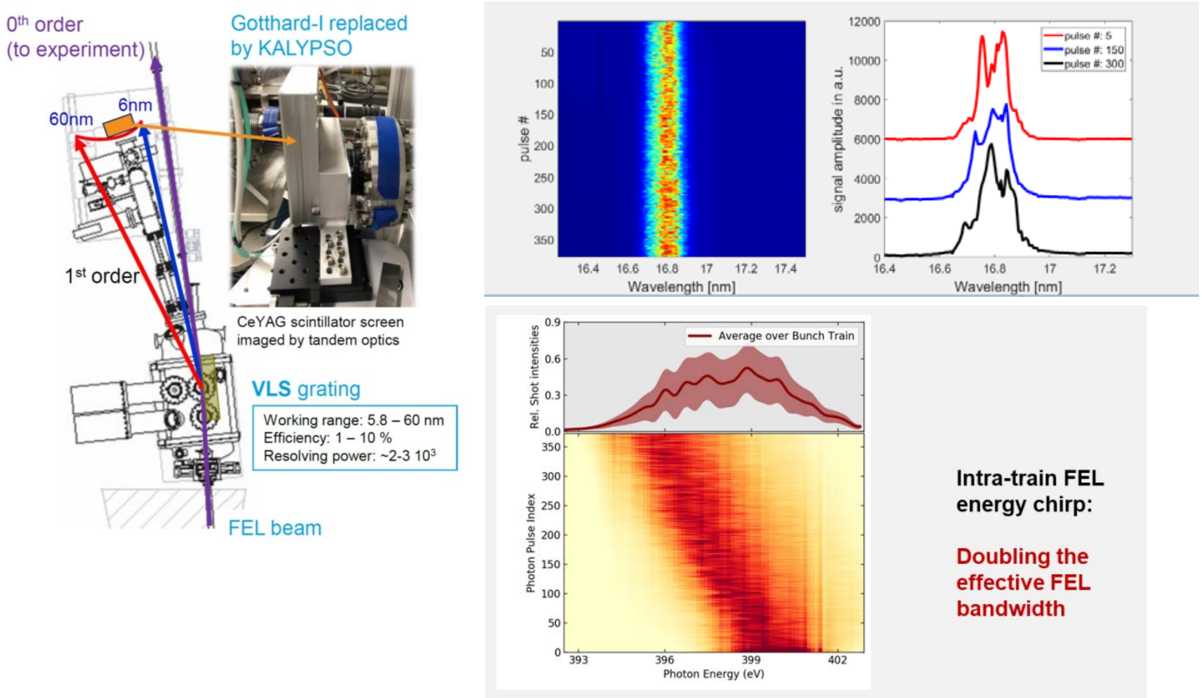

Figure 2: Left: Sketch of the VLS Online Spectrometer, reflecting most of the FEL intensity in 0th order towards the experiment while using about 1-10% of the intensity to measure spectra online in 1st order, e.g. with the KALYPSO detector. Top right: Series of spectra of a full pulse train of – in this case – 380 bunches from the KALYPSO detector. The three individual spectra at right have been offset vertically for better distinction. Bottom right: controlled wavelength chirp across pulse train.

[3] L. Rota et al., *KALYPSO: linear array detector for high-repetition rate and real-time beam diagnostics*, Nucl. Instr. and Meth. A, in press; https://doi.org/10.1016/j.nima.2018.10.093

[4] G. Brenner et al., *First results from the online variable line spacing grating spectrometer at FLASH*, Nucl. Instr. and Meth. A **635**, 99–103 (2011); http://dx.doi.org/10.1016/j.nima.2010.09.134

[5] C. Gerth et al., *Linear Array Detector for Online Diagnostics of Spectral Distributions at MHz Repetition Rates*, submitted to J. Synchrotron Rad. (2019)

[6] S. Palutke et al., *Spectrometer for shot-to-shot photon energy characterization in the multi-bunch mode of the free electron laser at Hamburg*, Rev. Sci. Instrum. **86**, 113107(2015); http://dx.doi.org/10.1063/1.4936293

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New beamline FL21 with dedicated THz streaking end-station for pulse length diagnostics

A new beamline – FL21 – was recently installed in the FLASH2 experimental hall. FL21 is featuring two branches: The straight beamline provides an unfocused FEL beam that can be used for non-permanent photon diagnostics or exploratory experimental setups (Figure 3, right beamline). The typical FLASH end-station infrastructure (triggers, ADCs, ethernet, power, cooling water, pressurized air, vacuum interlock etc.) will be installed there. The second branch leads to a dedicated XUV pulse duration lab (on the left in Figure 3) in its own 3 x 4 m^2 laser safety enclosure (not shown). A splitting mirror at the branching can be used to geometrically cut a freely selectable fraction of the incident FEL beam and reflect it towards the pulse length diagnostics setup based on the THz streaking technique ([7] and refs. therein). Here, the FEL beam is focused by a 1.5 m toroidal mirror into a permanently installed experimental chamber containing a gas jet, several electron time-of-flight (TOF) detectors and other diagnostics. Single-cycle THz pulses generated by an IR drive laser will be used for the pulse duration measurement.

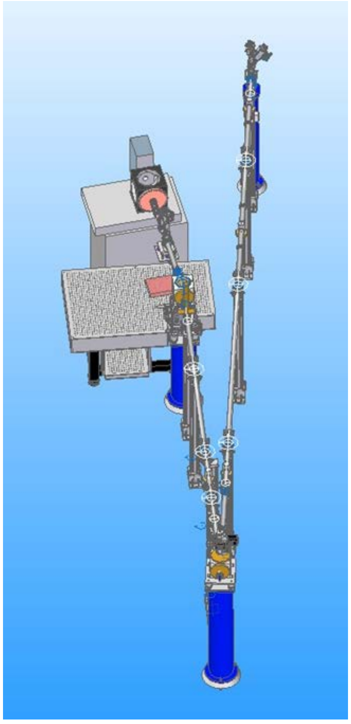

Figure 3: End of beamline FL21 with two branches: pulse length diagnostics (left) and open port for exploratory setups (right).

Further experience shall be gained here on the THz streaking measurement principle, involved measurement uncertainties and reachable resolution, to provide – medium term – a reliable pulse duration measurement setup. Thanks to the splitting mirror, a parallel online-measurement of the pulse duration together with an experiment in the straight branch is feasible. First pulse lengths diagnostics in combination with a test experiment are planned for spring 2019.

[7] R. Ivanov et al., *FLASH free-electron laser single-shot temporal diagnostic: terahertz-field-driven streaking*, J. Synchrotron Rad. **25**, 26-31 (2018); https://doi.org/10.1107/S160057751701253X

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Time-delay compensating monochromator beamline planned as FL23

For many research areas which require a narrower spectral bandwidth of the photon pulse than the natural bandwidth of FLASH, ultra-short pulse-lengths < 50 fs and high peak brightness are still prerequisites. An ultra-short pulse length can be preserved using a two-grating monochromator design ([8,9] and references therein). The user requirements for such a time-delay compensating monochromator were evaluated in a workshop in July 2017 and are summarized in Table 1.

Parameter		Value
Wavelength	(nm)	1.2 - 20.0 (including harmonics)
Pulse length	(fs)	< 50
Resolution	($\lambda/\Delta\lambda$)	≥ 2000
Flux at beamline end	(photons/pulse)	10^{10}

Table 1: User requirements for the Time-Delay Compensating Monochromator as basis for the FL23 beamline design.

The simulated performance in reference [8] shows that one can mostly reach these values, but might, at the long wavelength end, have to trade pulse length for resolution, because one reaches the Fourier limit.

To maximize the beamline throughput and the transmission efficiency, the number of optical elements is minimized in the Time-Delay Compensating Monochromator (TDCM) beamline. The TDCM is equipped with six optical elements: a planar elliptical mirror (EM), two variable line spacing (VLS) gratings (G1, G2) in reflection mode, a slit (S), a planar mirror (PM) and a bendable Kirkpatrick-Baez (KB) focusing system as shown in the sketch of the beamline in Figure 4.

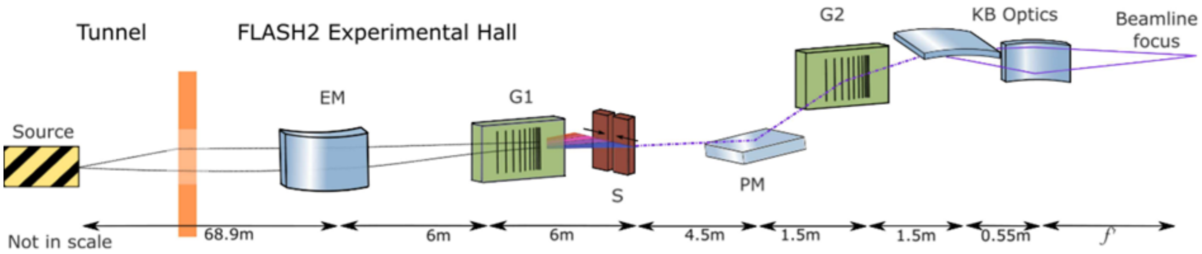

Figure 4: Schematic of the Time Delay Compensating Monochromator beamline FL23 (not to scale).

Meanwhile the new TDCM beamline FL23 is in the design and procurement phase and is expected to be installed and commissioned in 2021. With its medium resolution while preserving the pulse length and with its focus on the short wavelength range, it will very well complement the high resolution monochromator beamline PG at FLASH1.

[8] L. Poletto et al., *Double-grating monochromatic beamline with ultrafast response for FLASH2 at DESY*, J. Synchrotron. Rad. **25**, 131-137 (2018); https://doi.org/10.1107/S1600577517013777

[9] M. Ruiz Lopez et al., *Wavefront propagation simulations supporting the design of a time-delay compensating monochromator beamline at FLASH2*, J. Synchrotron Rad., accepted (March 2019)

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