SIMULTANEOUS MEASUREMENT OF ELECTRON AND PHOTON PULSE DURATION AT FLASH

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Abstract

One of the most challenging tasks for extreme ultraviolet, soft and hard X-ray free-electron laser photon diagnostics is the precise determination of the photon pulse duration, which is typically in the sub 100 fs range. In a larger campaign nine different methods, which are able to determine such ultrashort photon pulse durations were compared at FLASH [1]. Radiation pulses at a wavelength of 13.5 nm and 24.0 nm together with the corresponding electron bunch duration were measured by indirect methods like analyzing spectral correlations, statistical fluctuations and energy modulations of the electron bunch, and also direct methods like autocorrelation techniques, THz streaking or reflectivity changes of solid state samples.A detailed description of the measurement campaign can be found in Ref. [2].

THE IDEA

One of the main characteristics of the new generation XUV to X-ray free-electron lasers is their ultrashort pulse duration in the femtosecond range. With these new sources ultra-fast reaction dynamics on the femtosecond time scale [3–5] can be investigated. It also allows the investigation of multi-photon processes in the XUV [6] to the X-ray range [7] which has not been possible before. The accurate knowledge of the FEL key parameters such as pulse peak power, radiance, and on-target irradiance for example is crucial for the analysis of experimental data. It turns out that the number of photons, the focal spot size and the spectral content in such short pulses can be measured reliably [8–11], while the pulse duration is still the most difficult parameter to be determined.

At FLASH [1] the duration of the generated photon pulses can be varied over a range of few tens of femtoseconds up to several 100s of fs. Still, a reliable method to measure pulse durations for the entire parameter range is not yet available. Although a variety of methods have been proposed, they all need to be set-up and tested experimentally to find out the best suited technique. In a campaign nine different techniques – three electron bunch duration measurements and six photon based methods – have been used to determine the photon pulse duration. They are either performed in a *direct* way by measuring the photon pulse duration at the experimental end stations or on the other hand by *indirect* methods measuring only parameters which are linked – by theoretical models – to the actual pulse duration. From the measured information the actual XUV pulse duration can be calculated using these models. From the experimental point of view, indirect methods are typically simpler to realize as compared to the direct approaches. However, they have to be verified and calibrated by direct methods. So far only photon pulse duration measurement campaigns using one (or two) measurement technique have been undertaken at FLASH in the last years [12–17]. Up to now there were no studies at FLASH or at any other XUV/X-ray FEL where many different methods were compared within one dedicated pulse duration measurement campaign as shown in Fig. 1.

The main motivation for this study was three-fold. Firstly, we wanted to address the question how well the results measured by the indirect methods agree with the direct ones. What are the error bars when comparing the different methods? How much information about the photon pulse duration can we deduce from the electron beam parameters in contrast to the photon based methods? Secondly, the realization of all nine techniques together under the same beam conditions allows a direct comparison of advantages and disadvantages of the individual techniques. Thirdly, the aim of the campaign was to identify sensitive parameters of the electron bunch compression and to develop recipes for routine operation to reliably establish a specific user requested XUV pulse duration at FLASH, especially for ultrashort pulses below 50 fs. The detailed description of all methods and the comparison of the various approaches can be found in the extended paper Ref. [2].

CONCLUSION

The FEL was tuned such that all pulses in the bunch train had roughly the same electron bunch and XUV pulse parameters for the measurements that were performed at 13.5 nm. For this case a remarkably good agreement between all methods was found. Most of all it was shown that all used indirect methods reveal the same results as the direct methods and thus the assumptions made for the analysis of the indirect methods seem to be valid for this case. On the other hand, when the electron pulse and thus the XUV parameters were significantly changing within the bunch train, as in the case when the FEL was running at 24 nm, a strong deviation between different methods was observed. Here it is difficult to judge which method can be trusted to what extend.

While in SASE mode of operation the photon pulse is shorter than the total length of the electron bunch from which it is generated, the assumption of a factor 0.6 [2, 17] between the two can only be used as a very simple rule of thumb for first estimations. The measurements as well as start-to-end simulations showed, the factor can be substantially smaller depending on the accelerator settings. Due to the complicated beam dynamics in the energy range FLASH is working in, parameters like slice emittance and energy spread also have to be taken into account as well. Up

ISBN 978-3-95450-133-5

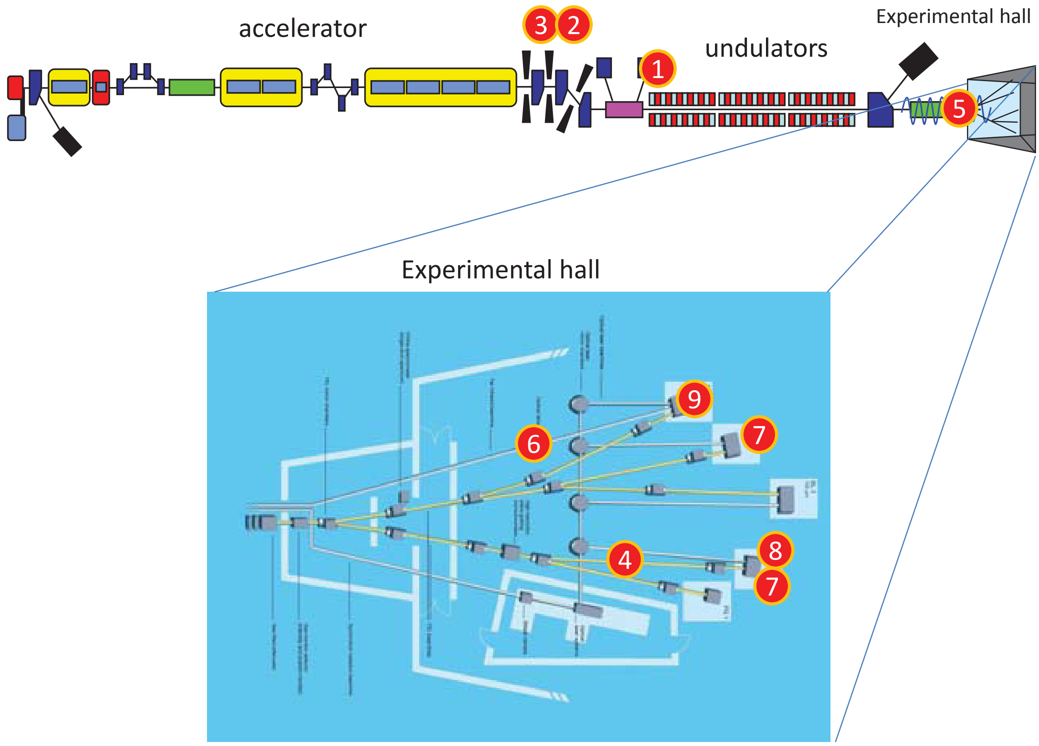

Figure 1: Schematic layout of the FLASH accelerator and the experimental hall (not to scale). The total length of the facility is 315 m. The positions of the various techniques for electron bunch or photon pulse duration measurements are indicated by numbers: (1) Transverse Deflecting RF Structure (TDS), (2) Bunch Compression Monitors (BCM), (3) THz Spectrometer CRISP, (4) XUV Spectra, (5) XUV Statistics, (6) Optical Replica (Afterburner), (7) XUV Autocorrelation (gas phase), (8) XUV Autocorrelation (solid state), (9) THz Streaking. A detailed description of the measurements can be found in Ref. [2].

to now we can only state that a universal scaling factor between electron and photon pulses could not be determined for FLASH.

ACKNOWLEDGEMENTS

The author wishes to acknowledge the work of the scientific and technical team at FLASH. The presented work was performed by the participants of the pulse duration campaign: M. Rehders, A. Al-Shemmary, C. Behrens, G. Brenner, O. Brovko, M. DellAngela, M. Drescher, B. Faatz, J. Feldhaus, U. Frühling, N. Gerasimova, N. Gerken, C. Gerth, T. Golz, A. Grebentsov, E. Hass, K. Honkavaara, V. Kocharian, M. Kurka, Th. Limberg, R. Mitzner,R. Moshammer, E. Plönjes, M. Richter, J. Rönsch-Schulenburg, A. Rudenko, H. Schlarb, B. Schmidt, A. Senftleben, E. Schneidmiller, B. Siemer, F. Sorgenfrei, A. Sorokin, N. Stojanovic, K. Tiedtke, R. Treusch, M. Vogt, M. Wieland, W. Wurth, S. Wesch, M. Yan, M. Yurkov, H. Zacharias, and S. Schreiber.

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ISBN 978-3-95450-133-5