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Optical laser-based THz streaking for full FEL pulse characterization

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Full temporal characterization of ultrashort, high brilliance x-ray pulses at Free Electron Laser (FEL) facilities, while elusive, will underpin their future use in experiments ranging from single-molecule imaging to extreme timescale x-ray science. This issue is especially acute when confronted with the characteristics of current generation FELs operating on the principle of self-amplified spontaneous emission, as most parameters fluctuate from pulse to pulse. We have achieved this crucial characterization by extending the techniques of photoelectron streaking originally developed for attosecond spectroscopy. In our experiments, high-intensity, optical laser generated single-cycle THz pulses were used to broaden and shift – or streak – the photoelectron spectrum of a noble gas target ionized by the incident FEL pulse. Due to the relatively long rise time of the THz streaking field (∼600 fs), these measurements allow for the arrival-time and temporal profile of femtosecond to hundred-femtosecond FEL pulses to be determined simultaneously and on a single-shot basis. Optical laser-based THz streaking is suited for use over the full range of photon energies and pulse durations produced at FELs, from XUV to the hard x-ray regime. Experiments have now been performed at the hard x-ray Linac-Coherent Light Source at the SLAC National Accelerator Laboratory as well as at the XUV Free Electron Laser in Hamburg. Distinct temporal features as short as 50 fs FWHM have been observed in the raw pulse profile prior to any correction for instrument resolution. While these first measurements have been resolution-limited, the potential for improvement to access the sub 10-fs range has also been demonstrated, which would allow for characterization and effective application of the shortest predicted, few-femtosecond x-ray pulses in the near future.