Machine learning applied to single-shot x-ray diagnostics at high-repetition rate XFELs

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X-ray free electron lasers (XFELs) are the only available sources able to produce bright few-fs fully-tunable x-ray pulses. Due to several factors, such as fluctuations in the accelerating radiofrequency field or the stochastic nature of SASE, they present considerable shot-to-shot fluctuations, requiring a full x-ray characterization for every shot, that can later be used for data sorting and data binning. Some of the devices involved in this characterization, such as XTCAV or even some spectrometers, will not be able to cope with the high repetition rate of the next generation of XFELs, limiting the effective repetition rate. We present a method that, using machine learning techniques and a small amount of training data from XTCAV and an x-ray spectrometer, can be used to predict single-shot spectral information and pump-probe delays using only fast electron bunch trajectory diagnostics, fast gas detectors and slow environment variables (temperature, chamber pressures) as inputs. Using the proposed method, we achieve a mean error below 1.6 fs when predicting the delay between two x-ray pulses, a mean error below 0.3 eV predicting the photon energy of the pulses, and an agreement better than 97% when predicting the spectral shape. Since all the fast variables used as input will be likely to be available at the MHz regime, this method will allow ultrafast spectroscopy experiments to take advantage of the full repetition rate of the next generation of XFELs.