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Deciphering FEL pulse profiles with autoencoder networks

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Free electron lasers (FEL) play an important role across diverse scientific disciplines. Many experiments can benefit from non-destructive photon diagnostics of provided FEL photon pulses. One method to obtain information about the pulse profile involves analyzing not the photons directly, but rather the energy distribution of the electrons downstream of a undulator [1]. While measuring the longitudinal phase space with a Transverse Deflection Structure (TDS) is relatively straightforward, obtaining the XUV pulse profiles can be challenging, especially with non-uniform current distributions, an energy chirp, or weak lasing pulses.

In recent times, artificial neural networks (ANNs) have gained widespread recognition as powerful analytical tools spanning various scientific domains, highlighted by this year's Nobel Prize in Physics awarded for contributions to ANNs. This potential suggests that these networks could assist in assigning a lasing off reference for each lasing on data point and therefore help to isolate the FEL lasing process in the data.
We present two case studies in which ANNs were applied to enhance the diagnostics of FEL photon pulse lengths with a TDS. The first case involves the use of beta-variational autoencoder (β-VAE) networks to characterize SASE X-ray pulses produced by the FLASH facility in Hamburg. We will discuss how data obtained from a Polarizable X-Band Transverse Deflection Structure (PolariX TDS) [2,3] allowed the β-VAE to identify SASE strength, a significant parameter in real-world data from FLASH. The second is a cooperation between SLAC and DESY where we used a U-net autoencoder network to enable the analysis of weak self-seeded X-ray pulses, where the weak lasing signal would make a classical analysis infeasible.
We will demonstrate both ANN approaches for pulse diagnostics using real-world data.

References:
[1] Behrens C. et al., Nat. Com. 5, 3762 (2014), https://doi.org/10.1038/ncomms4762 [2] Craievich P. et al., Phys. Rev. Accel. Beams 23, 112001 (2020), https://doi.org/10.1103/PhysRevAccelBeams.23.112001 [3] Christie F. et al. , Proceedings of FEL2019 (2019) https://doi.org/10.3204/PUBDB-2019-03833

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