From laser-plasma accelerator experiments to digital twins: Exploit machine learning methods to tighten the links between theory and experiment

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Building high-fidelity digitial twins through start-to-end models to better understand and control advanced laser-plasma accelerators, as well as compact free-electron laser beamlines, requires direct comparison to experimental data. We highlight recent results in start-to-end simulations and developments with a focus on their connection to experiment, such as by synthetic diagnostics and experimental data reconstruction analyses.

Live-visualization for experimental data aquisition

Providing data integration for laser-plasma accelerator experiments requires a flexible infrastructure that is easily extendable and can be accessed straight-forward. This not only eases the everyday operations of experimentalists, but also enables fast development and deployment of machine learning methods. Therefore, we propose a novel combination of several existing components such as mongoDB, Grafana, and Kafka, to approach this task. The data, which is ingested live during the experiments, is visualized using interactive plots in an easy-to-access Grafana dashboard.

Surrogate model to identify electron injection

The plasma dynamics in laser-plasma accelerators are in most cases inaccessible to direct measurements. The emitted radiation from the electrons inside the plasma, however, contains information about the electron motion and thus about the relevant plasma dynamics but is hard to interpret and thus does not allow for direct interpretation. We propose an invertible-neural-network (INN) based method, radINN, that is capable of translating the emitted radiation spectra to the amount of injected charge over time. The model was trained using synthetic radiation spectra from large-scale particle-in-cell simulations. Its capabilities in identifying the injection process using "wave-breaking radiation" already exceed the capability of human domain experts.

Towards digital twins of LPA driven FELs

Understanding and control of Laser-driven Free Electron Lasers remain to be difficult problems that require highly intensive experimental and theoretical research. The gap between simulated and experimentally collected data might complicate studies and interpretation of obtained results. In this work we developed a deep learning based surrogate that could help to fill in this gap. We introduce a surrogate model based on normalising flows for conditional phase-space representation of electron clouds in a FEL beamline. Achieved results let us discuss further benefits and limitations in exploitability of the models to gain deeper understanding of fundamental processes within a beamline.