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Data-Driven Modeling for Wakefield Colliders - New Capabilities for Integrated RF & Wakefield Modeling in BLAST

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Kinetic simulations of relativistic, charged particle beams and advanced plasma accelerator elements are often performed with high-fidelity particle-in-cell simulations, some of which fill the largest GPU supercomputers. Self-consistent modeling of wakefield accelerators for colliders includes many elements beyond plasma acceleration. The integrated Beam, Plasma & Accelerator Simulation Toolkit (BLAST) provides high-performance simulation codes suitable to model different parts of a beamline on the latest and world's largest GPU supercomputers. Yet, for some workflows such as start-to-end modeling and coupling with experimental operations (digital twins), it is desirable to integrate and model all accelerator elements with very fast, effective models. Traditionally, analytical and reduced-physics models fill this role, usually at a cost of lower fidelity and/or reduced dynamics.

Here, we show that the vast data from high-fidelity simulations and the power of GPU-accelerated computation open a new opportunity to complement traditional modeling: data-driven surrogate modeling through machine learning (ML). We present the new capabilities for fully GPU-accelerated, in-the-loop ML workflows in BLAST and how they complement and fill a need alongside first-principles modeling and reduced models and pair well with recently established out-of-the-loop machine-learning workflows (i.e., optimization). We demonstrate that the high-quality data from WarpX simulations can train low-error surrogate data models, which are seamlessly integrated into a GPU beamline simulation using ImpactX, with the purpose of minimizing chromatic emittance growth during acceleration and transport in a staged laser-wakefield accelerator of low beam charge.

Working group

WG1 : Laser-driven plasma wakefield acceleration

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