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Unravelling ultrashort dynamics of plasma-based accelerators – leveraging synthetic diagnostics to match PIC simulations with experimental data

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Exascale computing has recently become a reality. PIConGPU has paved the way to accelerating plasma simulations across compute platforms using the Alpaka framework. These capabilities not only enables conducting high-fidelity parameter scans of start-to-end simulations modeling experiments at full 3D3V geometry, but also make it possible to include additional physics.

However, experience has shown that the real challenges are of a different nature. Not only has the increasing quality of experiments put more demand on simulation quality, but more and more the need for fast analysis has grown. Based on recent experiment-driven simulation campaigns, we present results elucidating the LWFA bunch evolution within complex gas targets with plasma lensing, the injection dynamics of micro-structured LWFA bunches from CTR measurements and the pre-plasma dynamics in solid-density targets, correlating proton energies with reflected HHG radiation spectra. Here, we put an emphasis on synthetic diagnostics for radiation processes (HHG, CTR and scattered probe lasers) and atomic physics beyond the thermal equilibrium. We discuss I/O, code coupling, visual analytics and large-scale data analytics workflows to match experiment and provide an outlook on how feedback loops between experiment and simulation can be optimized.

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