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From Compact Plasma Particle Sources to Advanced Accelerators with Modeling at Exascale

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Research of plasma-based accelerators has achieved significant milestones over the last decade. Highlights include achieving nearly 8 GeV electrons in a single-stage source, demonstrating plasma-based FELs, reaching stable proton acceleration of ultra-short, nC-class pulses that enable studies into ultrahigh dose rate radiotherapy. As the exploratory aspect of the field benefits significantly from the elucidation of fundamental processes through simulations, transitioning from intriguing sources to scalable accelerators requires universally integrated, quantitatively predictive capabilities for design and operations.
In this presentation, we discuss that complex, reliable advanced accelerators require a coordinated, extensible, and comprehensive approach in modeling, from source to the end of the beam's lifetime. We will discuss approaches and highlights of ongoing Exascale Computing efforts in the community, both in the US and internationally. This includes laser-plasma modeling on an exaflop supercomputer using the US DOE Exascale Computing Project WarpX [1-4] as well as progress of PIConGPU in the OLCF Center for Accelerated Application Readiness (CAAR) project for the same machine, and further projects.
Leveraging developments for Exascale, the DOE SCIDAC-5 Consortium for Advanced Modeling of Particle Accelerators (CAMPA) will advance numerical algorithms and accelerate community modeling codes in a cohesive manner: from beam source, over energy boost, transport, injection, storage, to application or interaction. Such start-to-end modeling will enable the exploration of hybrid accelerators, with conventional and advanced elements, as the next step for advanced accelerator modeling. Following open community standards [5], one can initiate an open ecosystem of codes [6,7] that can be readily combined with each other and machine learning frameworks. These will cover ultrafast to ultraprecise modeling for future hybrid accelerator design, even enabling virtual test stands and twins of accelerators that can be used in operations.

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