Towards Exascale Simulations of Laser Plasma Interaction

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Simulations of Laser Plasma Interaction drive the field of laser-driven accelerators since its beginnings. Yet, their predictive powers have been limited by several key aspects. First, many codes were and are still unable to fully exploit the computational power available in modern supercomputers. This is both due to the fact that we are facing a zoo of programming models and hardware architectures as well as to the fact that the main algorithm, the particle-in-cell technique, is itself memory-bound and thus usually does not show peak performance floating point capability.

Second, comparison to experimental results is limited both by the limited knowledge on key experimental parameters as well as limited reproducibility in experiments. This means that in order to represent an experiment by simulation one has to perform a parameter survey rather than a single simulation.

Third, comparison to experimental results must take into account the variation in input parameters to the simulation, e.g. phase space distribution of macro-particles, numerical variations due to the choice of model, e.g. Maxwell solver, and the variation in model predictions itself. Quantifying these variations via error bars requires to increase parameter surveys even further.

Fourth, comparison to experimental results requires synthetic diagnostics that match the diagnostics used in the experiment as best as possible, since many diagnostics measure plasma properties via indirect processes that should be included in deriving results from simulation, e.g. K-alpha radiation as a measure for temperature.

Finally, open standards are mandatory for creating reproducible results, thus open file formats, open source codes and even open data are key requirements to foster progress of the research field.

We emphasize that all these prerequisites for predictable simulations demand computational power beyond what is available now, both in simulation and (subsequent) data analysis. Yet, with increasing experimental diagnostic capabilities and experimental control comparison to experiment becomes critical for optimizing laser plasma acceleration both in performance and robustness. We will thus show possible steps towards Exascale particle-in-cell simulations and data analysis using recent results on laser particle acceleration as illustrative examples.