Multi-parameter Bayesian optimization of laser-driven ion acceleration and synchrotron emission in PIC simulations

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Progress toward machine learning (ML)-driven feedback and control of laser-plasma interaction experiments has developed significantly in recent years. This approach is now opening a new pathway to realising applications of laser-plasma sources by guiding efficient and rapid exploration of the accessible experimental parameter space.

We have developed a software library called BISHOP which supports the implementation of ML-driven feedback and optimization of particle-in-cell simulations. Using this library, we report on the application of a ML model, involving Bayesian optimisation and generated by particle-in-cell data, to directly optimise the outputs of PIC simulations.

Using this approach we demonstrate the optimization of proton acceleration, driven by the interaction of a high-power laser pulse with a thin foil target [1]. Optimal laser and plasma conditions are identified four times faster for two input parameters, and approximately one thousand times faster for four input parameters (see Figure 1), when compared to systematic and linear parametric variation. In addition, a non-trivial optimal condition for the target front surface density scale length is discovered, which would have been difficult to identify by single variable scans.

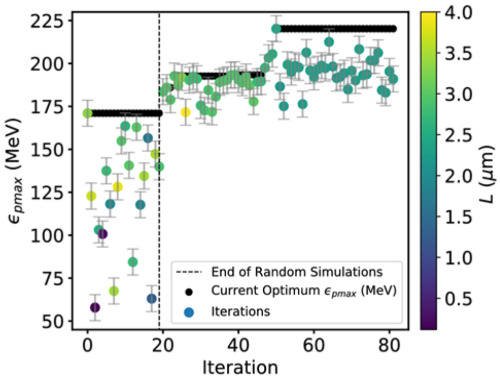

Figure 1: Maximum proton energy as a function of the iteration number of a Bayesian optimisation procedure in which the 4 input parameters are varied

The optimum parameters for the generation of synchrotron radiation in laser-foil interactions in the QED-plasma regime is also demonstrated with the application of Bayesian optimisationto 2D particle-in-cell simulations [2]. Individual properties of the synchrotron emission, such as the yield, are maximised, and simultaneous mitigation of bremsstrahlung emission is achieved with multi-variate objective functions. These optimisation results highlight the laser angle-of-incidence as a crucial parameter to maximise the generation of synchrotron radiation. This is further explored in 3D simulations. The results demonstrate the utility of applying a Bayesian optimisation approach and provide key new insights into the underpinning laser-plasma interaction physics.

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References
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