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Surrogate Modeling of Laser-Plasma-Based Ion Acceleration with Invertible Neural Networks

The interaction of overdense and/or near-critical plasmas with ultra-intense laser pulses presents a promising approach to enable the development of very compact sources for high-energetic ions. However, current records for maximum proton energies are still below the required values for many applications, and challenges such as stability and spectral control remain unsolved to this day. In particular, significant effort per experiment and a high-dimensional design space renders naive sampling approaches ineffective. Furthermore, due to the strong nonlinearities of the underlying laser-plasma physics, synthetic observations by means of particle-in-cell (PIC) simulations are computationally very costly, and the maximum distance between two sampling points is strongly limited as well. Consequently, in order to build useful surrogate models for future data generation and experimental understanding and control, a combination of highly optimized simulation codes (we employ PIConGPU), powerful data-based methods, such as artificial neural networks, and modern sampling approaches are essential. Specifically, we employ invertible neural networks for bidirectional learning of parameter and observables, and autoencoder to reduce intermediate field data to a lower-dimensional latent representation.

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