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Machine Learning-Based Diagnostics and Control of Dielectric Laser Acceleration

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Dielectric Laser Acceleration (DLA) is a promising technology for compact electron accelerators, capable of achieving accelerating gradients far beyond those of conventional radiofrequency cavities. Dielectric nanostructures are used to shape the near-fields of ultrashort laser pulses to accelerate electrons. However, introducing advanced laser shaping techniques, such as pulse front tilts or higher order dispersion, adds significant experimental and operational complexity. These setups involve many parameters that require precise control and optimization. Machine learning (ML) has proven to be a valuable tool in improving the performance of traditional accelerators. In this talk, we present the implementation of an ML-based control system for DLA experiments at the ARES facility at DESY. This system reconstructs and optimizes the laser pulse shape using diagnostic data from the post-DLA electron beam. A deep neural network built with PyTorch is trained on simulation data generated by a symplectic 6D tracking code. These simulations have been benchmarked against experimental results from interaction between electrons and laser pulses with different pulse shapes. We further refined hyperparameters for accurate reconstruction and evaluated DLA-specific structures and diagnostics to address ambiguities. Ultimately, this system serves as a virtual diagnostic to actively optimize DLA performance.

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