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Adaptive machine learning with hard physics constraints and generative diffusion for 6D phase space diagnostics

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Machine learning (ML) tools have been growing in popularity for accelerator applications, but still struggle with time varying systems, for which they require lengthy brute-force re-training. LANL has developed generative machine learning (ML)-based tools, that utilize adaptive model independent feedback control theory together with hard physics constraints, to make the tools much more robust to distribution shift. These adaptive ML tools are able to extrapolate much further beyond the span of the training data and are thus much more robust for time-varying systems. This talk will give a broad overview of the challenges of various time-varying accelerator systems at various accelerator facilities (known as systems with distribution shift in the ML community) and will present adaptive ML tools for 6D phase space diagnostics of intense charged particle beams. The talk will give a general overview of diffusion-based generative models and also adaptive latent space tuning, which is the novel method we have developed for adaptive ML, and how we are strictly enforcing hard physics constraints in our ML tools, which traditional ML tools lack. We demonstrate our general methods for various accelerators: the 5-meter long ultra-fast electron diffraction (UED) HiRES compact accelerator at LBNL, the ˜kilometer long plasma wakefield accelerator FACET-II at SLAC, and the LANL ion accelerator LANSCE.

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Primary author: SCHEINKER, Alexander (Los Alamos National Laboratory)

Presenter: SCHEINKER, Alexander (Los Alamos National Laboratory)

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