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Advances in Machine Learning Based Modeling and Control of Particle Accelerators at Scientific User Facilities

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Particle accelerators are used in a wide array of medical, industrial, and scientific applications, ranging from cancer treatment to understanding fundamental laws of physics. While each of these applications brings with them different operational requirements, a common challenge concerns how to optimally adjust controllable settings of the accelerator to obtain the desired beam characteristics. For example, at highly flexible user facilities like the Linac Coherent Light Source (LCLS) and FACET-II at the SLAC National Accelerator Laboratory, requests for a wide array custom beam configurations must be met in a limited window of time to ensure the success of each experiment —a task which can be difficult both in terms of tuning time and the final achievable solution quality.

At present, the operation of most accelerator facilities relies heavily on manual tuning by highly-skilled human operators, sometimes with the aid of simplified physics models and local optimization algorithms. As a complement to these existing tools, approaches based on machine learning are poised to enhance our ability to achieve higher-quality beams, fulfill requests for custom beam parameters more quickly, and aid the development of novel operating schemes.

I will discuss recent developments in using ML for online optimization, the creation of ML-enhanced virtual diagnostics to aid beam measurements, and the use of ML to create fast-executing online models (or "digital twins") of accelerator systems. These improvements could increase the scientific output of particle accelerator user facilities and enable new capabilities in creating custom charged particle beams. They could also help us to meet the modeling, design, and online optimization challenges that become more acute as we push toward the more difficult-to-achieve beam parameters that are desired for future accelerator applications (e.g. higher beam energies and intensities, higher stability, and extreme adjustments of the beam shape in phase space).

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