# Adaptive Machine Learning for Control and Virtual Diagnostics of Time-Varying Particle Accelerator Systems and Beams*

Alexander Scheinker
Los Alamos National Accelerator (LANL)

## Abstract

Particle accelerators and their beams are uncertain time-varying systems. Accelerators are composed out of thousands of coupled components including RF cavities and magnets. RF cavities are constantly perturbed by disturbances such as temperature drifts which translate into phase shifts and vibrations which cause a change in resonance and introduce both phase and amplitude shifts. Magnetic fields are perturbed by power source ripple and suffer from history-dependent hysteresis effects. All of the components are imperfectly aligned and their field profiles are usually only estimated. The accelerated beams themselves are also uncertain and time-varying objects due to fluctuations in sources and complex collective effects such as space charge forces and coherent synchrotron radiation. The results of time-variation and uncertainty is that machines differ from existing models and continuously change with time which translates into lengthy tuning procedures following shutdowns and when making large changes in beam characteristics such as bunch lengths, bunch charge, and energy. The problem is further exacerbated by the fact that only limited non-invasive online beam diagnostics are available which typically measure only 1D or 2D projections of the beam's 6D (x,y,z,px,py,pz) phase space. The fields of adaptive feedback control and machine learning (ML) both have the potential to aid in controlling charged particle beams and in developing new non-invasive diagnostics and we present some examples of such work. One of the major challenges faced in applying ML methods to accelerators is the fact that the accuracy of trained ML tools quickly degrades for time-varying systems. For accelerators repeatedly collecting massive new data sets for re-training is not feasible. We present recently developed adaptive machine learning (AML) methods designed for time-varying systems by combining robust model-independent feedback control with ML tools such as generative encoder-decoder convolutional neural networks. We show how adaptive feedback and AML tools can aid in automatic control of charged particle beams and provide virtual phase space diagnostics.

* Title and Abstract of an Invited Presentation at the Workshop: AI/ML for Particle Accelerator, X-Ray Beamlines and Electron Microscopy at Argonne National Laboratory, November 1-3, 2021.