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Optimizing the Discovery of Underlying Nonlinear Beam Dynamics in Angular Momentum and Space Charge Dominated Beams

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One of the Grand Challenges identified by the Office of High Energy Physic relates to the use of virtual particle accelerators for beam prediction and optimization. Useful virtual accelerators rely on efficient and effective methodologies grounded in theory, simulation, and experiment. Typically, virtual accelerators are created using either computationally expensive simulations or black box methods like Machine Learning (ML). The underlying nonlinear dynamics governing beam evolution can be challenging to interpret and understand with such techniques. Our work interweaves simulation, theory, and experiment to gain deeper insight into the constituent physics.
We are developing an experiment related to Derbenev's flat-to-round and round-to-flat transformations, designed to match electron beams from a high energy storage ring into and a solenoidal cooling channel. Our research focuses on discovering underlying nonlinear beam dynamics. We are using a linear transport system with a design optimized by applying a computationally efficient adjoint optimization technique developed by our group. We will explore cases of low and significant space charge with substantial angular momentum. We will concurrently be comparing simulations in WARP to beam measurements and reoptimizing the design as needed to test alternative experimental configurations. We will use an algorithm called Sparse Identification of Nonlinear Dynamical systems (SINDy) to learn the governing nonlinear beam dynamics. SINDy has not previously been applied to beam physics. We believe the SINDy methodology promises to simplify the optimization of accelerator design and commissioning, particularly where space charge is important. At NAPAC'22, as an example, we used SINDy to identify the underlying differential equations governing beam moment evolution. We compared discovered differential equations to theoretical predictions, results from WARP, and prior work using ML. Finally, we propose extending our methodology to the broader community's virtual and real experiments.

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