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Fast 6-Dimensional Phase Space Reconstructions using Generative Beam Distribution Models and Differentiable Beam Dynamics

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Next-generation accelerator concepts, which hinge on the precise shaping of beam distributions, demand equally precise diagnostic methods capable of reconstructing beam distributions within 6-dimensional phase spaces. However, the characterization of intricate features within 6-dimensional beam distributions using conventional diagnostic techniques necessitates hundreds of measurements, using many hours of valuable beam time. Novel diagnostic techniques are needed to substantially reduce the number of measurements required to reconstruct detailed, high dimensional beam features as feedback in precision beam shaping applications. In this study, we present a novel approach to analyzing experimental measurements using generative machine learning models of 6-dimensional beam distributions and differentiable beam dynamics simulations. We demonstrate in simulation that using our analysis technique, conventional beam manipulations and diagnostics can be used to reconstruct detailed 6-dimensional phase space distributions using as few as 20 beam measurements with no prior training or data collection. These developments enable detailed, high dimensional phase space information as online feedback for precision control of beam distributions in advanced accelerator applications and can be used to improve our understanding of complex accelerator beam dynamics.

Primary Keyword

transformers

Secondary Keyword

differentiable models

Tertiary Keyword

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