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Efficient 6-dimensional phase space reconstructions from experimental measurements using generative machine learning

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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 position-momentum spaces. However, the characterization of intricate features within 6-dimensional beam distributions using current diagnostic techniques necessitates a substantial number of measurements, using many hours of valuable beam time. Novel phase space reconstruction techniques are needed to reduce the number of measurements required to reconstruct detailed, high-dimensional beam features in order to resolve complex beam phenomena, and as feedback in precision beam shaping applications. In this study, we present a novel approach to reconstructing detailed 6-dimensional phase space distributions from experimental measurements using generative machine learning and differentiable beam dynamics simulations. We demonstrate that this approach can be used to resolve 6-dimensional phase space distributions from scratch, using basic beam manipulations and as few as 20 2-dimensional measurements of the beam profile. We also demonstrate an application of the reconstruction method in an experimental setting at the Argonne Wakefield Accelerator, where it is able to reconstruct the beam distribution and accurately predict previously unseen measurements 75x faster than previous methods.

Footnotes

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