Contribution ID: **35** Type: **Contributed Oral**

Detailed Phase Space Reconstructions from Accelerator Beam Measurements Using Differentiable Simulations

Wednesday, 9 November 2022 14:00 (15 minutes)

Characterizing the phase space distribution of particle beams in accelerators is a central part of accelerator understanding and performance optimization. However, conventional reconstruction-based techniques either use simplifying assumptions or require specialized diagnostics to infer high-dimensional (> 2D) beam properties. In this work, we introduce a general-purpose algorithm that combines neural networks with differentiable particle tracking to efficiently reconstruct high-dimensional phase space distributions without using specialized beam diagnostics or beam manipulations. We demonstrate that our algorithm reconstructs detailed 4D phase space distributions with corresponding confidence intervals in both simulation and experiment using a single quadrupole and diagnostic screen. This technique allows for the measurement of multiple correlated phase spaces simultaneously, enabling simplified 6D phase space reconstruction diagnostics in the future.

Acknowledgments

This work was supported by the U.S. Department of Energy, under DOE Contract No. DE-AC02-76SF00515, the Office of Science, Office of Basic Energy Sciences and the Center
for Bright Beams, NSF award PHY-1549132.

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Session Classification: WGs 2+5 Joint Session

Track Classification: Working Group Parallel Sessions: WG2 Oral: Computation for Accelerator Physics