Online Bayesian Optimization of Electron Beam Phase Space Shaping

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Introduction

Particle accelerators require adjustment of system settings to control the final electron beam characteristics for different applications. At present, this optimization process is often done manually by human operators by visual inspection. Electron beam transport can involve collective effects, making their control not intuitive for human operators. We introduce an online optimization method that directly incorporates images of the electron beam as well as a desired target distribution into a metric in order to automatically shape the beam towards the target distribution.

Phycical System

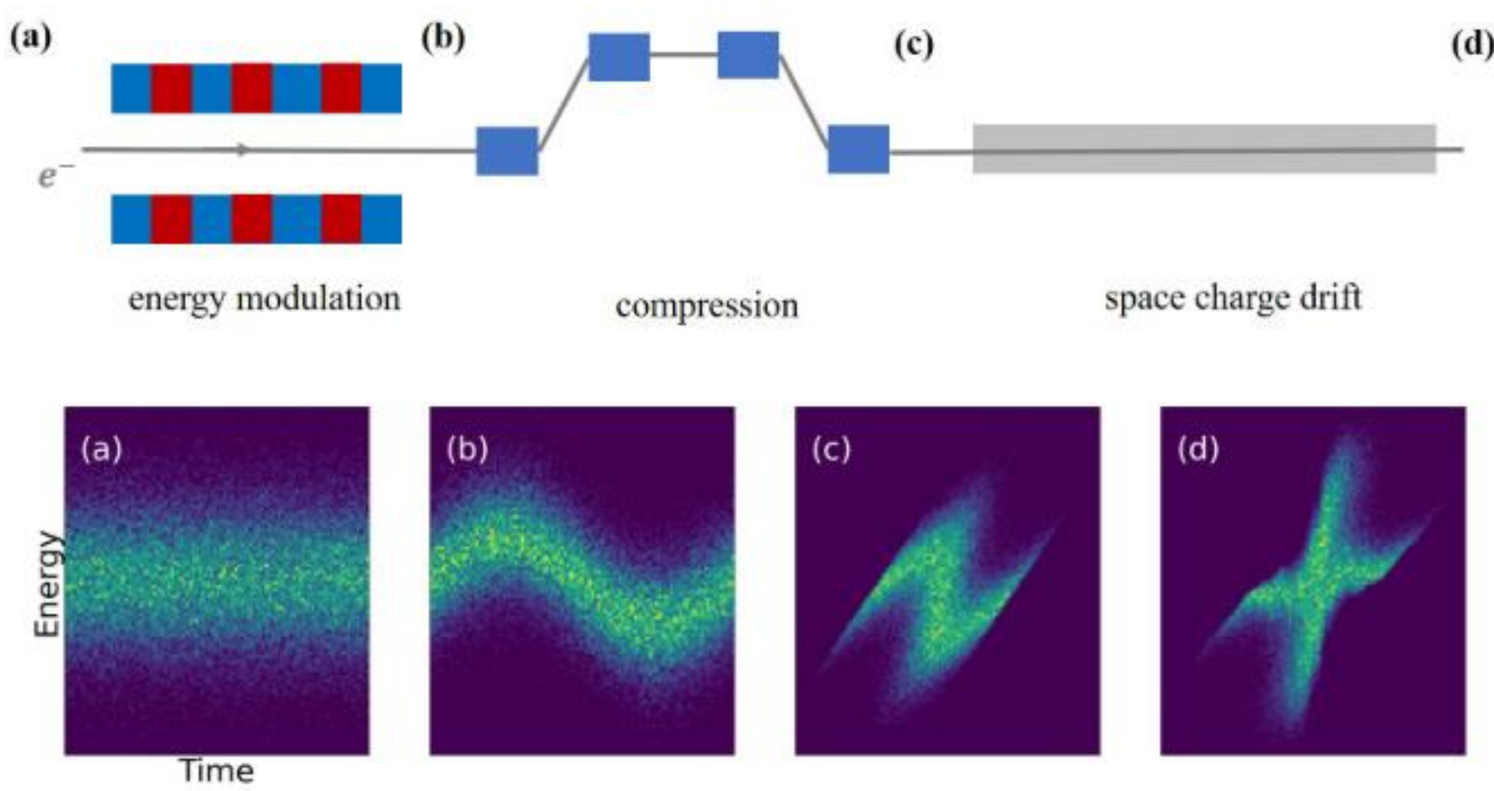

Figure 1: Physical System

In this work we use a simplified particle simulation of optical compression for enhanced self amplified spontaneous emission FEL (Free Electron Lasers) scheme as an example and focus on creating a "spike" in the phase space.

Methods and Results

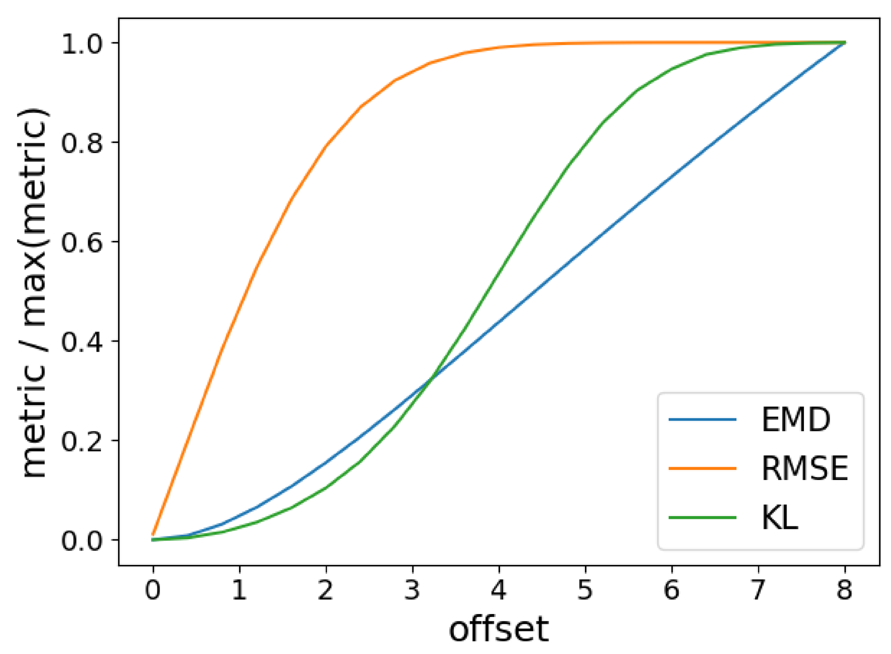

Figure 2: Metrics to compare two displaced normal distribution

A Metrics

There are multiple metrics for comparing the similarity of the two distributions. We choose EMD as our main metric due to its capability to provide effective information on totally disjoint distributions.

B Bayesian Optimization

We use Bayesian optimization to control the parameters of the physical system in order to minimize the difference between the target and measured distributions. A radial basis function (RBF) with automatic relevance determination plus white noise are used as our kernel.

C Comparison in *k* space

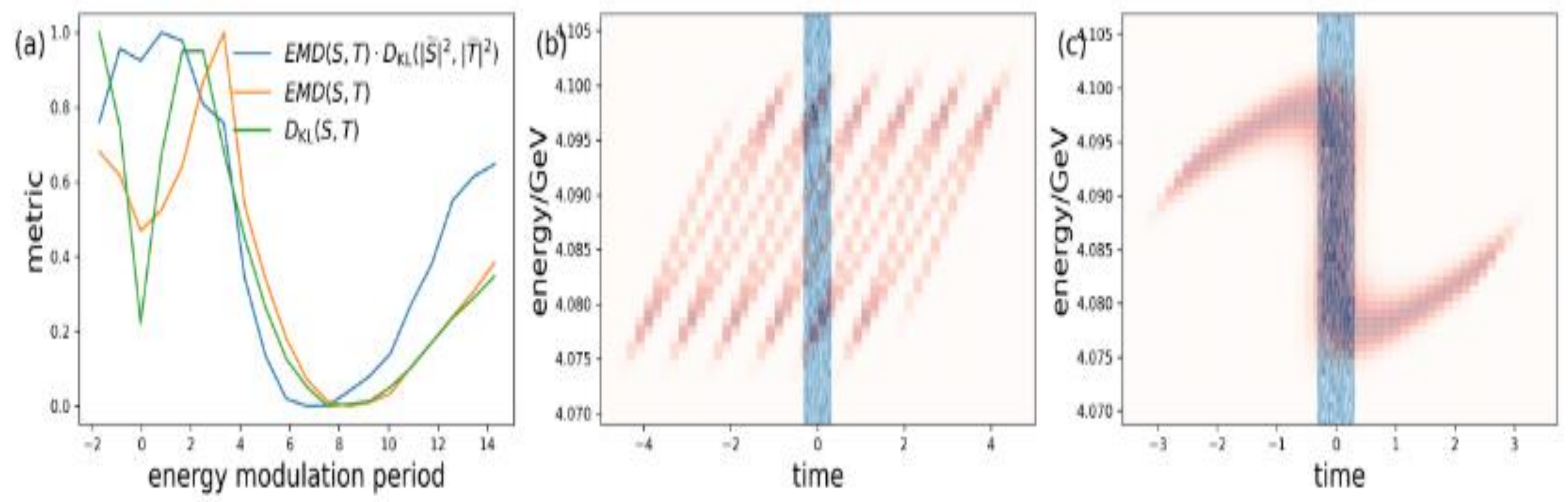

Figure 3: Combined Metrics to mitigate local minimum

An complication in the test case is that a local minimum exists when producing multiple spikes while targeting a single spike. We used a combined metrics measuring the KL divergence in k space as well to mitigate the effects.

D Automatic beam shaping

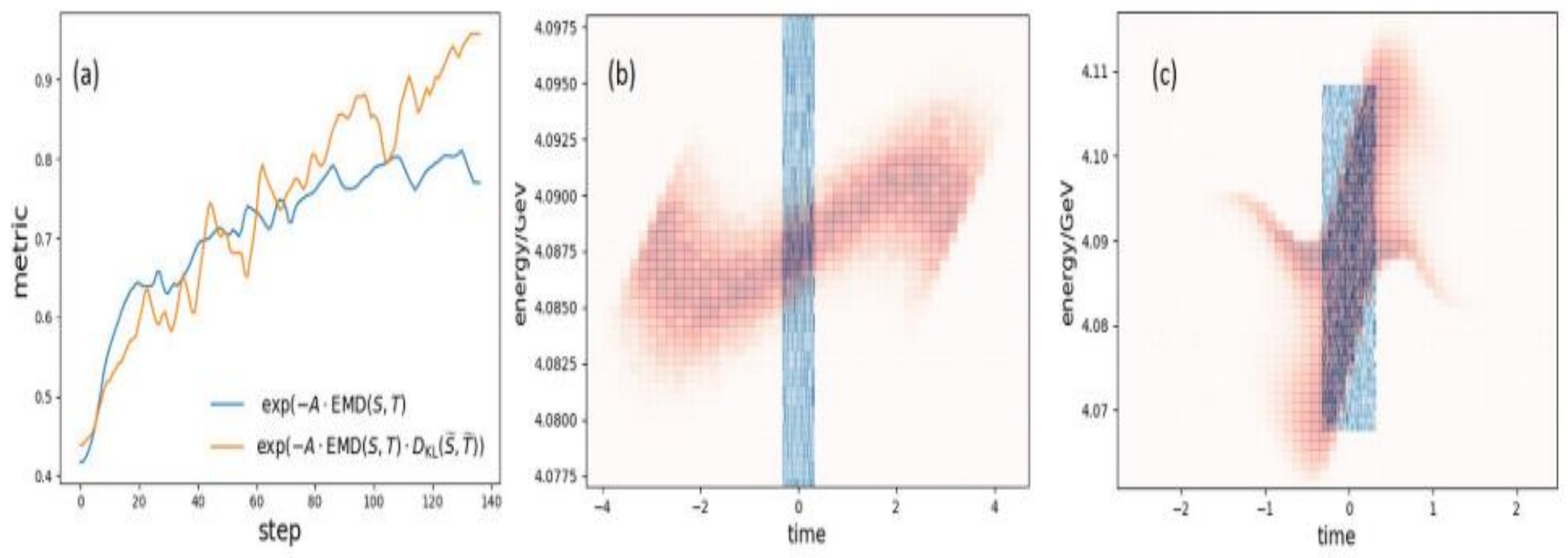

Figure 4: Automatic beam shaping with Bayesian Optimization

Future Work

The use of temporally shaped infrared (IR) laser could enable control of electron phase space down to the femtosecond time scale at high repetition rate, which is desirable in the next generation of high-average power x-ray FELs such as Linac Coherent Light Source-II (LCLS-II). We propose to use Bayesian optimization for online control of the laser shaping.

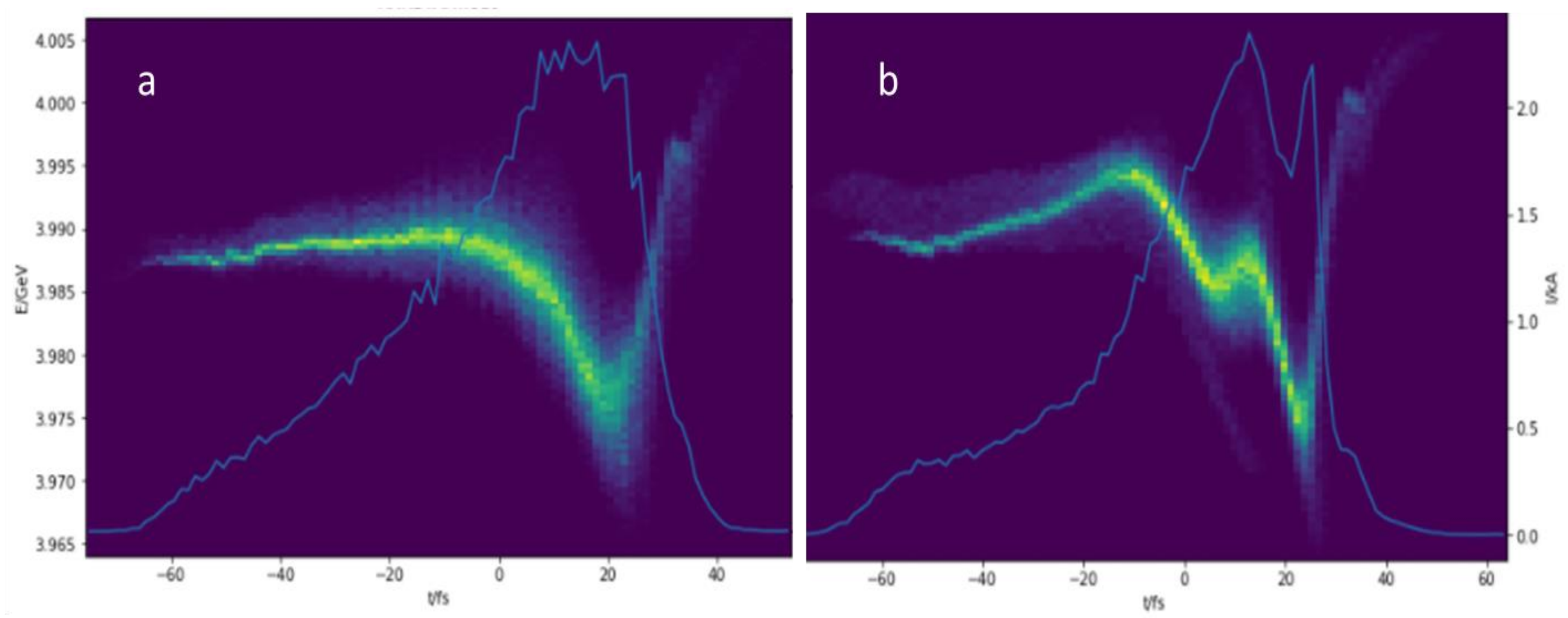

Figure 5: LCLS-II beam (a) before and (b) after laser shaping.

[1] Physical Review Letters, 124(12):124801, 2020
[2] Physical Review Letters., 116:254801, Jun 2016
[3] Physical Review Letters, 119(15):154801, 2017.
[4] Nature Photonics, 14(1):30–36, 2020.