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EXPERIMENTAL DESIGNS OF COHERENT SYNCHROTRON RADIATION IN COMPLEX BEAMS

O. H. Ramachandran[1,2*], G. Ha[1,2], C.-K. Huang[3], X. Lu[1,2], J. Power[2], and Ji Qiang[4]

[1]Northern Illinois University, DeKalb, IL 60115, USA
[2]Argonne National Laboratory, Lemont, IL 60439, USA
[3]Los Alamos National Laboratory, Los Alamos, NM 87545, USA
[4]Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA

Abstract

Coherent synchrotron radiation (CSR) is one critical beam collective effect in high-energy accelerators, which impedes the generation of high-brightness beams. The Argonne Wakefield Accelerator (AWA) facility is unique in the experimental investigation of CSR effects in complex beams, offering a large parameter space for the bunch charge and size, various bunch profiles (round and flat beams), and the capability of generating shaped bunches through both laser shaping and the emittance exchange approach. This presentation will outline planned experiments at AWA and their designs, including a CSR shielding study using a dipole chamber with a variable gap size, and the effect of CSR on the beam phase space in a laser-shaped short electron bunch. This work is part of a comprehensive study involving self-consistent CSR code development and experimental investigation. The experimental component aims to provide benchmarking with the advanced codes under development, explore the boundaries of 1/2/3D CSR effects on beam dynamics, evaluate CSR effects in complex beams, and eventually propose CSR mitigation strategies.

INTRODUCTION

Advances in the understanding of beam collective effects, including space charge and radiative effects like coherent synchrotron radiation (CSR), are of crucial importance in the generation of high-brightness beams [1]. Designing accelerating structures that overcome the negative impact of collective effects requires advances in both fidelity of existing computational methods, as well as in accurate prediction and mitigation strategies.

* oramachandran@anl.gov

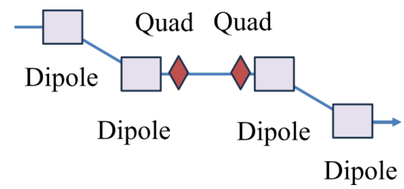

Figure 2: Beamline schematic for the proposed experiment. The addition of the two quadrupole magnets effectively converts the EEX dipoles to a reversed chicane.

To that end, progress has been made on the development of self-consistent simulation tools [2] rather than 1D analytical models [3]. By leveraging the features of these methods, we can now begin the probe the impact of collective effects on highly complex beams.

In this work, we describe the first of a sequence of planned experiments at the Argonne Wakefield Accelerator (AWA) that aims to leverage the wide range of beam parameters, layouts and profile shapes available on the Emittance Exchange (EEX) to benchmark the self-consistent simulation tools. The complete physical insight gleaned from both theoretical and experimental advances will provide an important step in the long-term development of HEP accelerators.

EXPERIMENTAL GOALS AND OVERVIEW

The primary objectives of the upcoming experiment at the AWA are to (1) probe CSR effects in bunches with longitudinally shaped current profiles and (2) to benchmark the influence of the CSR shielding effect.

Beamline Layout

The experiment will be conducted on the emittance exchange (EEX) beamline, outlined in Fig. 1. In the interest of keeping as much of the existing beamline intact as possible

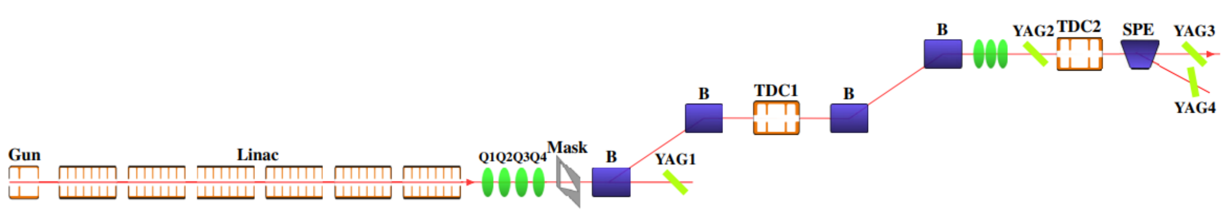

Figure 1: The EEX beamline at the AWA. B, TDC, Q and SPE refer respectively to a dipole magnet, transverse deflecting cavity, quadrupole magnet and spectrometer.

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to reduce delays, we plan to insert two quadrupole magnets in the 4 dipole sequence as shown in Fig. 2. The addition of the quadrupoles provides a transfer matrix of $\begin{pmatrix} -1 & d \\ 0 & -1 \end{pmatrix}$, which effectively reverses the second dogleg to create a reversed chicane. Sensitivity analysis was performed on the quadrupole strengths and from the plot in Fig. 3, we are able to tolerate the 2% error in the field strength required for beamline operation.

CSR Effects on Longitudinally Shaped Beams

The use of longitudinally shaped current profiles has been shown theoretically to potentially mitigate the effects of CSR [4]. In this phase of the experiment, our goal is to benchmark the effects of CSR on bunches with different longitudinal profiles. To generate pulses with the requisite sharp features, the AWA uses a laser temporal pulse stacker (TPS) with a series of 5 α-BBO birefringent crystals. Specific pulse shapes can be optimized by manipulating the orientation of each BBO, as shown in Fig. 4. We are currently working on optimizing a set of beamline, injector and BBO settings that allow for the target profile to be generated at the entrance to the reversed chicane, thereby allowing us to isolate (as much as possible) the CSR effects on the bunch.

CSR Shielding Effects

Another goal of the upcoming experiment is to probe the CSR shielding effect by tuning the variable gap size in the AWA dipole chamber shown in Fig. 5. In particular, the variable gap size can be systematically tuned to measure the sensitivity in the longitudinal phase space. The insights and data gleaned from this experiment will aid in the validation of a novel self-consistent CSR simulation method that is currently being developed as part of the larger project.

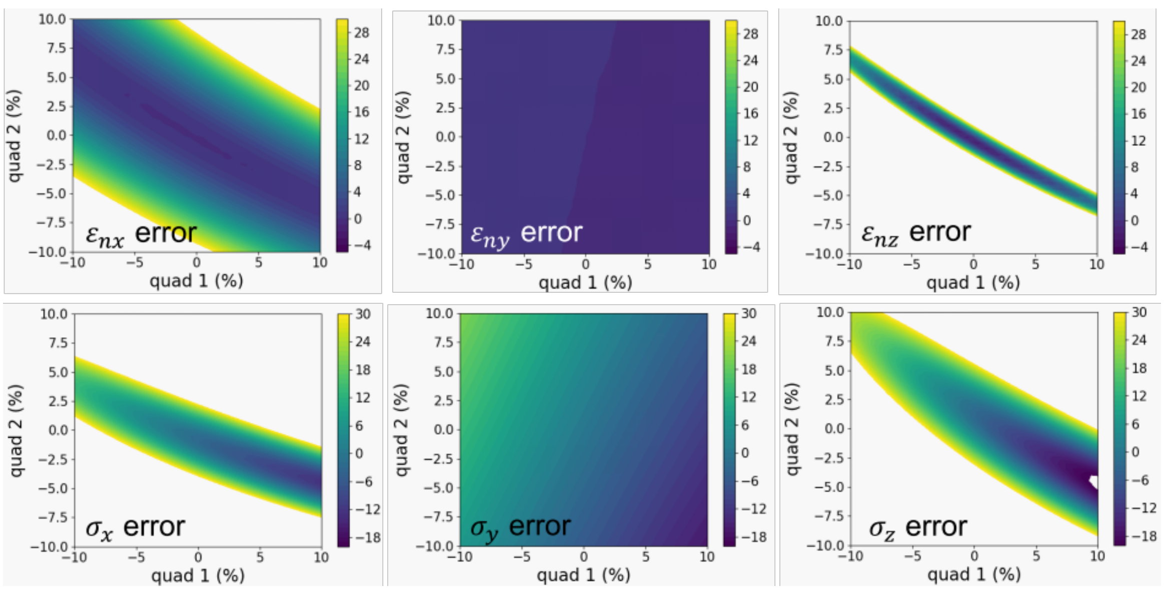

Figure 3: Sensitivity analysis for tuning the strength of the two quads in Fig. 2. The top and bottom rows depict the errors in emittance and beam size components respectively.

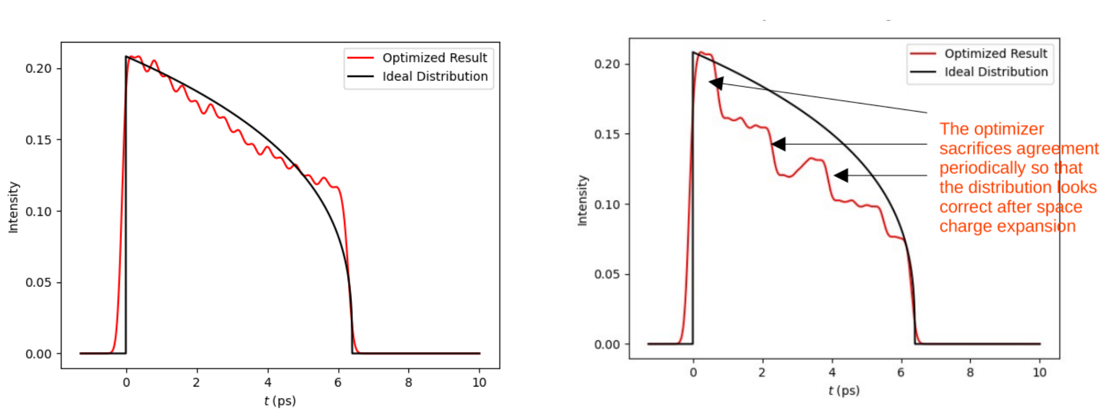

Figure 4: Two laser profile optimization results where the target profile is as described in [4]. (Left) the orientation of the α-BBO crystals were tuned in order to match the profile at the gun. (Right) α-BBO crystal orientations were tuned to produce the target profile while compensating for 2m of space charge expansion.

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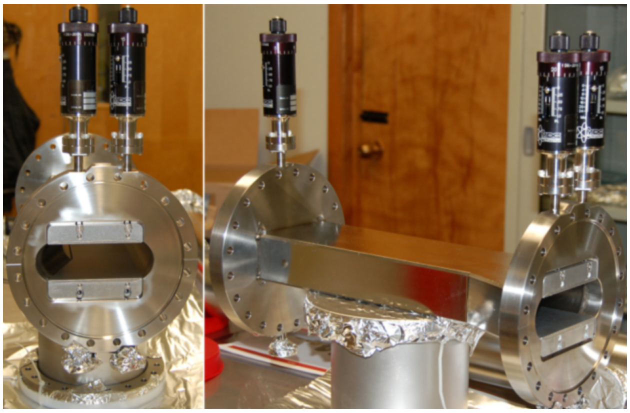

Figure 5: Photograph of the AWA dipole chamber with a adjustable gap size.

CONCLUSION

The planned sequence of experiments at the AWA aims to characterize the effects of CSR and eventually provide the possibility of formulating designs that minimize collective effects on beam quality. In this work, we have outlined the immediate experiment planned for the Summer and showcased a few early design and simulation results.

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