EXPERIMENT ON SUPPRESSION OF SPONTANEOUS UNDULATOR RADIATION AT ATF*

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Abstract

We propose undertaking a demonstration experiment on suppressing spontaneous undulator radiation from an electron beam at BNL's Accelerator Test Facility (ATF). We describe the method, the proposed layout, and a possible schedule.

INTRODUCTION

There are several advantages in strongly suppressing shot noise in the electron beam, and the corresponding spontaneous radiation.

The self-amplified spontaneous (SASE) emission originating from shot noise in the electron beam is the main source of noise in high-gain FEL amplifiers. It may negatively affect several HG FEL applications ranging from single- to multi-stage HGHG FELs [1]. SASE saturation also imposes a fundamental hard limit on the gain of an FEL amplifier in a coherent electron-cooling scheme [2].

A novel active method for suppressing shot noise in relativistic electron beams by many orders-of-magnitude was recently proposed [3]. While theoretically such strong suppression appears feasible, the performance and applicability of this novel method must be evaluated experimentally. Several practical questions about the proposed noise suppressor, such as 3D effects and/or sensitivity to the e-beam parameters also require experimental clarification. To do this, we propose here a proof-of-principle experiment using elements of the VISA FEL at BNL's Accelerator Test Facility.

We plan to tune the system using clearly observable dependencies on the system's gain, G, and the relative

SHOT-NOISE SUPPRESSOR

Fig. 1 is a schematic of the proof-of-principle for a laser-based suppressor of shot-noise and spontaneous radiation for a relativistic electron beam. The shot-noise (spontaneous radiation) suppressor system comprises of two short wigglers tuned at the wavelength of a broadband laser-amplifier, a transport system for the electron beam around the laser, and the buncher.

The suppressor works as follows: The electron beam passes through the first wiggler where it spontaneously emits radiation proportional to the local values of shot noise. Then, this radiation traverses a high-gain, broadband laser amplifier. In the second wiggler, an electron interacts with the amplified radiation induced by the neighboring electrons, and accordingly, its energy is changed.

The energy change is transferred in a microscopic phase-shift (arrival time) in a buncher. The sum of these microscopic shifts in amplitudes is equal to the amplitude and opposite in sign to the initial shot-noise harmonic. The outcome is the suppression of this harmonic in the beam's density.

PROOF-OF-PRINCIPLE SET-UP

Passing through such a system, the electron beam should become noise-free within the suppressor's bandwidth. . Hence, the spontaneous radiation and SASE radiation within this range of the spectrum will be suppressed strongly when the laser-amplifier is tuned. optical phase between the electron and its amplified radiation when they enter the second wiggler, ϕ.

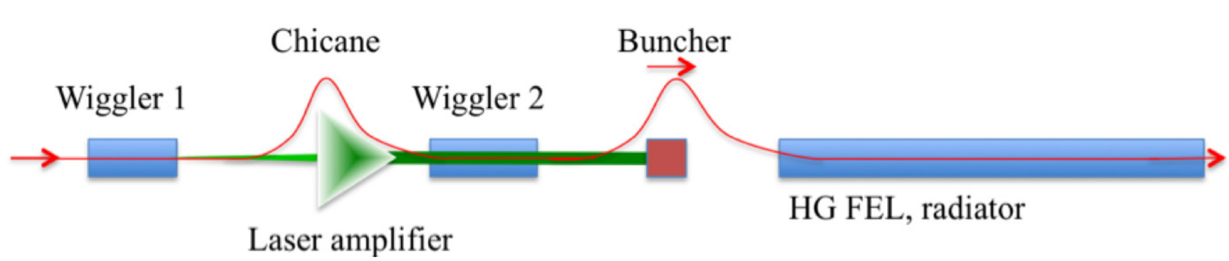

Figure 1: Layout of our proposed proof-of-principle experiment on suppressing spontaneous radiation from a relativistic electron beam. After the electron beam passes through the shot-noise suppressor, comprising two wigglers, a laser-amplifier, and the buncher [3], it should not generate either spontaneous or SASE radiation in the high-gain FEL.

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According to the theory developed in [3], the spectral-power density of the spontaneous radiation and SASE power will depend on these parameters as follows

$$P_{\omega} = P_{\omega}^{0}\left(1 - 2G\cdot\cos\phi + G^{2}\right), \quad (1)$$

where P_{ω}^{0} is the radiation power with the laser off. Small changes in the chicane's strength delaying the e-beam by few optical wavelengths will be used to scan the phase ϕ. In this case, the radiated power will follow a *cosine*-like modulation from its minimum value $P_{\min} = P_{\omega}^{0}(1-G)^{2}$ to its maximum value of $P_{\min} = P_{\omega}^{0}(1+G)^{2}$. The amplitude of the modulation will allow us to determine experimentally the gain of the system G, and set it at its optimum value $G = 1$. We will adjusting the gain of the shot-noise suppressor by changing the strength of the buncher and, if necessary, reducing it by introducing a controllable filter into the laser-pass.

LASER AMPLIFIER

High-gain wide-band laser amplifier is required for this application. However, it also is important to minimize the time a signal takes to pass from the first to the second wigglers. This requirement favors an amplifier with a single pass through the gain medium (compared to one wherein the light signal is bounced back and forth). Modern optical parametric amplifiers (OPAs) seemingly have all these features. Furthermore, they possess another attractive feature, viz., they do not need stored energy in the gain medium. This is not true for typical optical amplifiers that are based on population inversion in the gain medium.

Optical parametric amplification (Fig. 2) is described as a non-linear process wherein a short wavelength photon (from a narrow-band. high-power pump laser) is converted into two photons of longer wavelength, known as a signal and an idler [8].

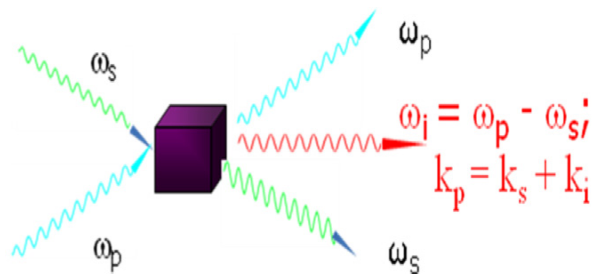

Figure 2: The principle of optical parametric amplification.

The input signal, properly polarized, can be introduced at either the wavelength of the idler or the signal. It enhances conversion via stimulating emission, and hence, assures amplification. The amplification gain-length (typically a few mm) is limited by the damage thresholds for a given optical power density.

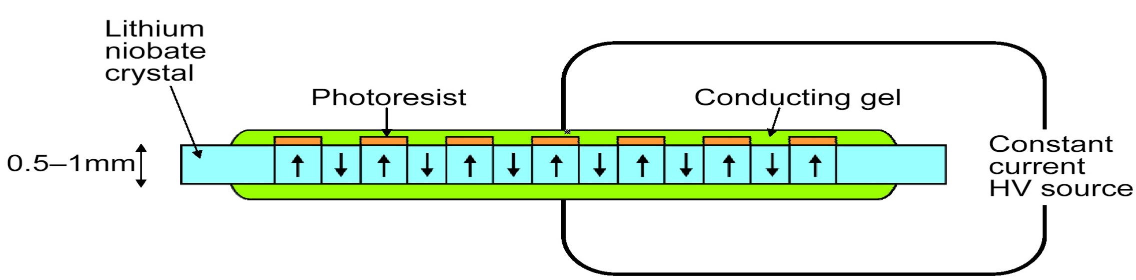

Figure 3: Scheme of periodically poled $LiNbO_3$.

We suggest using a lithium niobate optical parametric amplifier operating at wavelengths between 1.4 and 4.3 μm [4]. These amplifiers, carefully considered and evaluated for a scheme of optical stochastic cooling [5,6,7], offer very large amplification in a very short distance, and at very low noise.

Our present choice is to use an amplifier with bandwidth of 1.5-2 μm, and a wavelength of 1.75 μm for the experiment. In combination with the parameters of VISA FEL, this selection determines the choice of electron beam energy to be 47 MeV.

ACCLERATOR TEST FACILITY AT BNL

The Accelerator Test Facility (ATF) at Brookhaven National Laboratory (BNL) has been operating since 1992. The ATF is a dedicated proposal-driven, program-committee-reviewed user facility available for experimental research on plasma- and laser-acceleration of particles, beam-plasma physics, ultra-short pulse electron- and radiation-sources, advanced diagnostics, and high-brightness electron beams.

The ATF provides high-brightness electron beams (e.g. normalized rms emittance of 0.8 μm at a charge of 0.5 nC) at up to 75 MeV energy to four well-instrumented beam-lines (see Fig. 4). High-power laser beams synchronized to the electron beam are available at most of the beam lines. The bunch length is variable from 2 to 8 ps from the photoinjector. It can be further compressed with a new a bunch compressor down to 100 fs.

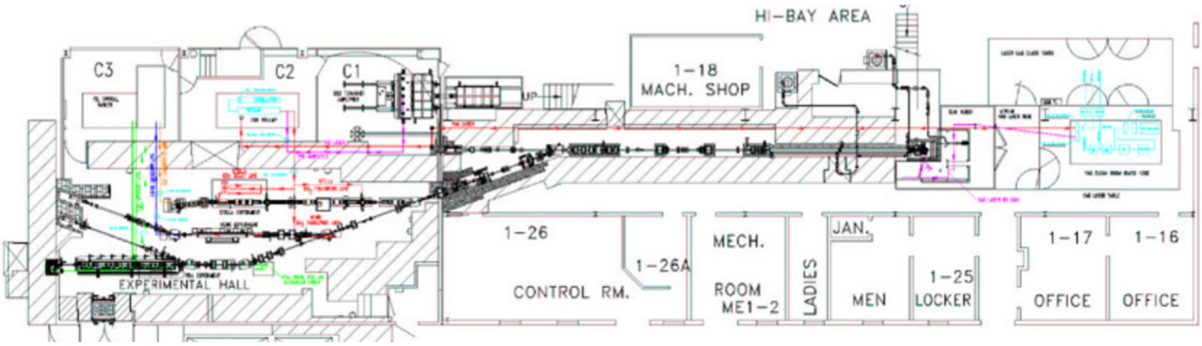

Figure 4: Layout of the Accelerator Test Facility at BNL .

Several important FEL experiments have been conducted for the first time throughout the years at the ATF. Notably, there was the first observation of self-amplified spontaneous emission in the near-infrared and visible wavelengths [9], the first demonstration of the High-Gain Harmonic-Generation Free-Electron Laser [10], and of the VISA program, including the characterization of the properties of the ultrashort gain length, self-amplified spontaneous emission free-electron laser in the linear regime and saturation [11]. The observation of an anomalously large spectral bandwidth in a high-gain self-amplified spontaneous emission Free-Electron Laser [12] is one latest VISA experiments at ATF.

We may partially modify beam line 3 in front of the VISA undulator (Fig. 5) and, possibly, add a dog leg to accommodate the two short wigglers and the optical amplifier. We propose to use the wigglers of the VISA FEL and its diagnostics for this experiment.

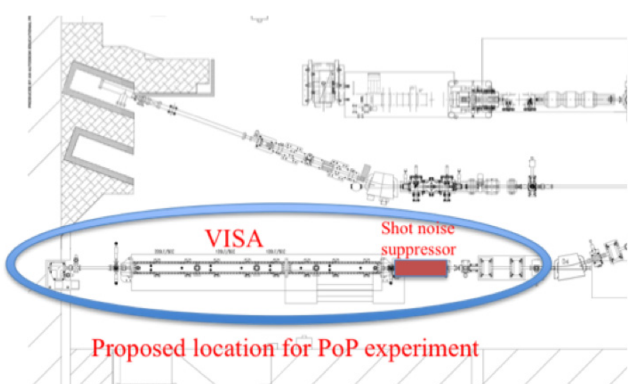

Figure 5: Proposed location for our proof-of-principle experiment on suppressing spontaneous radiation from the relativistic electron beam.

DISCUSSION

The new elements that we will add to beam-line 3 are two short wigglers, a chicane, a buncher, and the laser-amplifier pass and its optics. i.e., our new suppressor itself. The suppressor will require a completely new vacuum chamber. After installing and commissioning these components, we propose conducting a series of experiments of increasing complexity.

The first experiment we will undertake will be to demonstrate shot-noise suppression by observing both the modulation and, ultimately, strong suppression of spontaneous radiation from a single VISA wiggler. Our goal in this experiment will be to check the validity of shot-noise suppression in the e-beam density. It would not require a high peak current or extremely good beam quality.

Our second experiment would focus on demonstrating the suppression of SASE radiation from a high gain VISA FEL, i.e., will necessitate a high-quality beam and the full length of the VISA FEL. Our objective will be to demonstrate that we can suppress the dominant growing mode in the SASE FEL. This experiment might extend to verify the suppression of high-order transverse modes via their collimation (see discussions in [3]). One potentially interesting test in this stage will be to demonstrate the amplification of a very weak external seed with a gain exceeding the limit of SASE FEL.

The Third experiment would test of DOK approach to noise suppression at arbitrary wavelengths without using an external laser-amplifier. In this case, we suggest to modify the VISA HG FEL into a DOK, and using the two first wigglers for the noise suppression and the remaining ones for amplification. It will be natural to start by employing the same wavelengths and the same diagnostics as in the first two stages, but to demonstrate later the full tunability of the suppressor within the tuning range of the ATF linac and VISA.

CONCLUSSIONS

The Accelerator Test Facility at BNL is perfectly suited for our proof-of-principle experiment that aims to demonstrate strong suppression of spontaneous emission from a relativistic electron beam, and suppression of power from SASE FELs.

With the flexibility of the facility, and the VISA high-gain FEL we can address the majority of questions about the practicality of this novel noise-suppression technique, as well about its scalability for short wavelength FELs.

If the experiment is approved, it would take about a year to modify beam-line 3, and to procure the necessary optical components. Hence, the first experiment could start in 2010 and be completed by within six months. The second experiment is more demanding; its execution may take about one year. We could complete the third experiment, requiring more modifications of the beam-line, in about two years. .

If successful, this technique will open new horizons for FEL, including the amplification of weak seeds and may lead to much more practical multi-stage HGHG FELs.

We would like to note that there is a proposal of using an alternative passive technique developed for low noise microwave devices [13], which is potentially applicable for extremely cold electron beams.

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