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Applications of Machine Learning in Compact Photoinjectors

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ACTIVITIES OF THE PROJECT

To configure a photoinjector to reproduce a given electron bunch with the desired characteristics, it is necessary to adjust the operating parameters with high precision. The fine-tunability of the laser parameters are of extreme importance as we try to model further applications of the photoinjector. The laser pulse incident on the photocathode critically affects the bunch 3D phase space.

Control of Electron Bunch

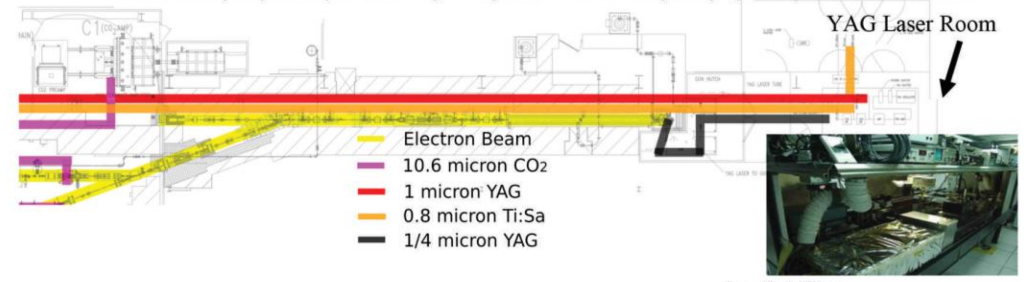
The ability to produce arbitrary laser intensity distributions enables better control of electron bunch transverse and longitudinal emittance by affecting the space-charge forces throughout the bunch

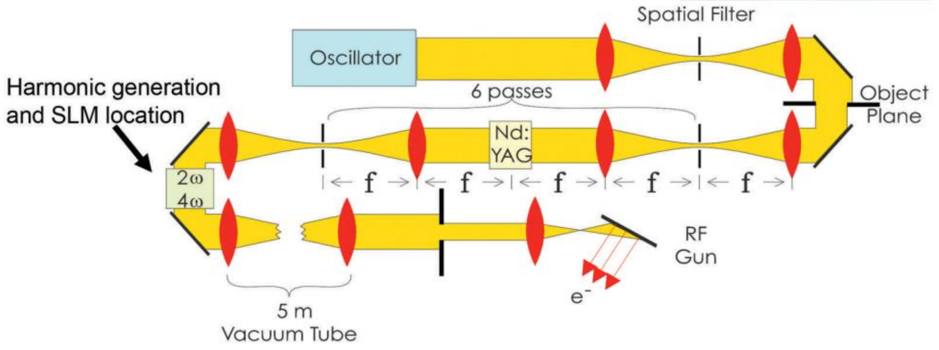
Parameter Control

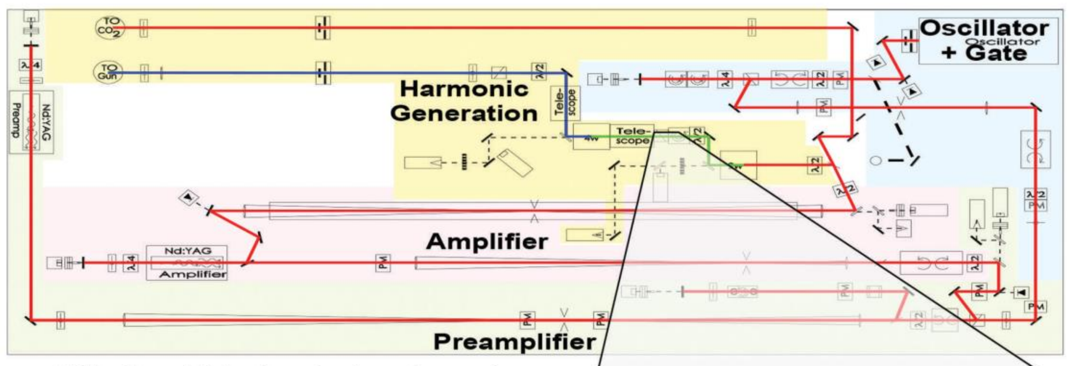
Parameters such as the Laser pulse transverse shape, total energy, and temporal profile (fixed) must be controlled independently, and undesired laser pulse variation over both short and long-time scales also requires correction.

FACILITY CONFIGURATION

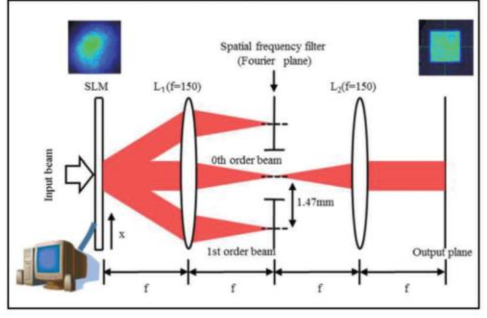
Laser delivery to photoinjector already incorporates Fourier relay imaging transport from laser room







- SLM will modulate phasefronts and cause beam reshaping through diffraction
- Inserting SLM between second and fourth harmonic generation crystals allows device to operate at optimum efficiency and damage threshold
- Modulated green beam profile is transferred to UV and imaged to photocathode
- Higher-order energy diffracted out of central beam is filtered by aperture or limited acceptance angle of fourth harmonic crystal (~few mradian)



LITERATURE REFERENCE

Ultraviolet laser transverse profile shaping for improving x-ray free electron laser performance

Li *et. al.* demonstrated that ultraviolet laser transverse profile shaping could be utilized to improve X-ray free electron laser performance [7].

The authors employed a digital micromirror device to control the shape of a 253 nm drive laser at the linear coherent light source.

However, due to the low damage threshold of the digital micromirror in the UV, the work is limited in its applications

Adaptive electron beam shaping using a photoemission gun and spatial light modulator

On the other hand, Maxson *et. al.* [8] used a SLM for shaping the drive laser of a dc photoemission gun.

The authors created a simple shaping algorithm which results in a detailed transverse laser shaping with very high fidelity.

An active feedback system was put in place which would take the unshaped electron beam image, and then create accurate detailed laser shaping further contributing to better efficiency.

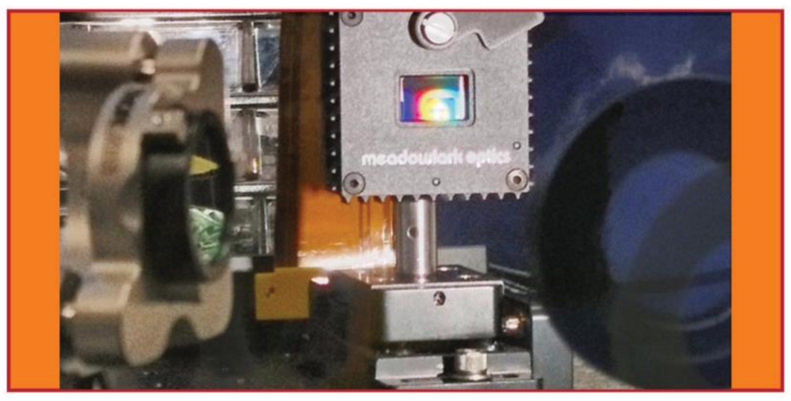
In an accelerator employing a photoinjector, electron optics in the beamline downstream of the injector are used to transport, manipulate, and characterize the electron bunch.

Delivering a laser pulse to the photocathode typically involves several optical elements to transport the pulse from the remote laser area to the radiation environment of the electron gun.

Shaping optics are usually placed close to the photocathode, and diagnostic elements are also as close to the photo-emission gun as possible to provide accurate measurements of laser parameters on the photocathode.

Commonly used metal photocathodes are very robust and long-lived in operation. Their work functions are 3-4 eV, and so UV laser pulses are used to generate photoemission, with typical wavelengths between 250-300 nm. This places stringent requirements on optical fabrication tolerances that are rarely achieved in practice.

Moreover, at high current photoinjector beam photocathode and its uniformity is disturbed through ion bombardment and increased vacuum pressure which thereby changes and alters the electron density from a given laser shape.



Partial mitigation of this effect and other detrimental effects is achieved by the use of Fourier relay imaging throughout the laser system and transport optics.

This optical configuration consists of a series of image planes transferred through the system by lens pairs in a 4f arrangement. An initial object plane is repeatedly imaged to critical elements such as amplifiers and harmonic generation crystals in the laser system, and finally to the photocathode.

This will also enable the use of a spatial light modulator (SLM) between the two harmonic generation crystals for intensity control of the second harmonic of the ATF Nd:YAG laser at 532 nm. Subsequent fourth harmonic generation and image relaying will allow the profile at the photocathode to be controlled and optimized.

TRAINING PROCESS METHODS

First Method

An image of the photocurrent can be formed downstream with the magnetic optics that reproduces the emission profile at the photocathode.

This profile can then be recorded by phosphor screen and camera. Image analysis will then permit the quality of fit between the ideal and measured emission profiles to be calculated and used as a fitness function to train the neural network.

Second Method

Second, at each iteration of the neural network-controlled laser profile, an emittance scan can be performed with the magnetic optics and beam profile monitors, and the beam emittance calculated for use as a fitness function

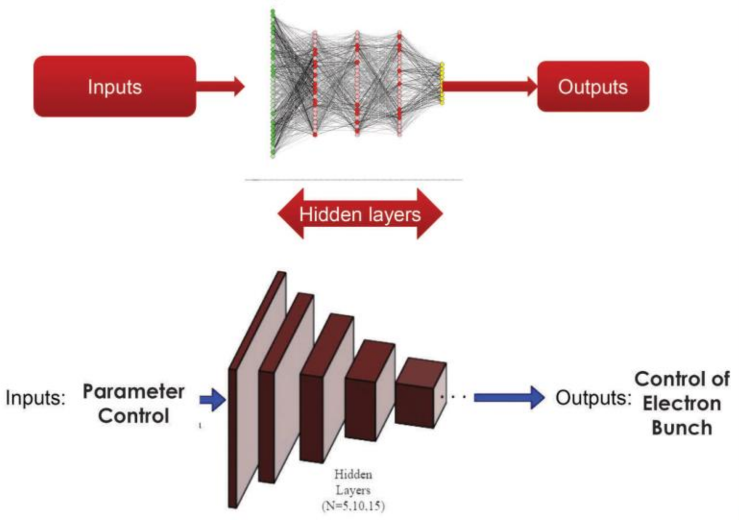
These two methods can be compared for efficiency and may prove to be complimentary.

In this project, we aim to use a liquid crystal based SLMs to control the transverse shape of the second harmonic of a Nd:YAG laser at 532 nm.

In order to enable optimization of laser profile for a specific photoinjector and electron beam parameters, a learning phase is required to train the neural network.

Experimental detail: Surrogate Model

We will apply Feedforward Neural Network (FFNN) with the different number of layers and with different Inputs. The feed-forward model is the simplest form of a neural network as information is only processed in one direction. While the data may pass through multiple hidden nodes. Schematic for the internal structure of the feedforward Neural Network is given below:



Developing the NN

The choice for training function is plenty especially for a FFNN such as:

- Levenberg-Marquardt.
  gradient descent method and Gauss-Newton method.
- Bayesian Regularization.
- Scaled Conjugate Gradient.
- Conjugate Gradient with powell/Beale Restarts.

Training and Testing process

- Levenberg Marquardt algorithm
- Tansig symmetric sigmoid transfer function
- Nguyen-widrow layer optimization
- Sequential order incremental adoption
- Gradient descent with momentum
- Mean squared error.
- 70% of the data will be taken for training, 15% for validation and 15% for testing.

Acknowledgement

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