

# NUMERICAL MODELING AND EXPERIMENTAL DATA ANALYSIS FOR DIELECTRIC LASER ACCELERATORS\*

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## Abstract

Work on Dielectric Laser Accelerators (DLAs) has been ongoing for the past decade. These devices come in a variety of configurations but share the use of lasers as power sources and dielectrics as the primary building material. While these devices have many of the same characteristics and dynamics as conventional accelerating structures, they operate in a dramatically different regime.

One version of these DLAs is the Micro Accelerator Platform (MAP): a slab-symmetric device operated with a standing wave (Pi-mode) and powered by a transversely coupled laser. The coupler is essentially a transmissive diffraction grating and therefore reinforces the desired mode. The remainder of the structure is composed of two Distributed Bragg Reflectors (DBRs) which serve to form a resonant cavity in an evacuated gap bounded by the reflectors. The MAP has now undergone experimental testing at SLAC's E-163. As with many advanced accelerators, identifying the best data analysis approach demands extensive numerical modelling of the anticipated beam parameters and development of data visualization and post-processing tools. We present the latest numerical results and data analysis tools developed for dielectric laser acceleration experiments with MAP.

## INTRODUCTION

The Micro Accelerator Platform (MAP) is a slab-symmetric device in which a vacuum gap is formed by the separation between two reflecting surfaces (distributed Bragg reflectors [DBRs], made from alternating layers of low- and high-index materials). An optical accelerator, the MAP is powered by a side-coupled laser and supports a standing-wave mode by which electrons can be synchronously accelerated. Development and testing of the MAP has been underway at UCLA for several years [1]. The resonant frequency of the accelerating mode is controlled by the thicknesses of the DBR layers and vacuum gap. A distributed grating element on the outer surface of one slab couples in laser power and also establishes and reinforces the periodic accelerating mode.

The MAP is designed to operate at a laser wavelength of 800 nm, which sets the scale for all its design parameters; the vacuum gap separation is equal to the laser wavelength. The DBR layers are one-quarter wavelength thick, and deposited on glass substrates of 0.5

mm thickness. The acceleration length is 1 mm, containing 1200 optical periods. Further details of the design and fabrication of the MAP can be found elsewhere in these proceedings [2].

In this paper, we describe the diagnostics required for ongoing experimental testing of the MAP via an externally injected electron beam at the Next Linear Collider Test Accelerator (NLCTA) facility at the SLAC National Accelerator Laboratory. The following sections include a brief description of the experiment, followed by simulation results; data analysis tools and future considerations.

## EXPERIMENTAL SETUP

A schematic of the experimental setup for MAP testing at the NLCTA is shown in Figure 1. A 60 MeV electron beam is focused at the MAP structure via permanent magnet quadrupoles (PMQs); focusing to a small spot optimizes the transmission through the sub- $\mu\text{m}$  acceleration gap. The beam energy after interaction with the sample is measured using a point-to-point focusing spectrometer magnet, which produces a correlation between the horizontal coordinate and beam energy on a scintillator screen imaged by an intensified camera (Princeton Instruments PI-MAX3 iCCD). Interaction of the beam with the IR laser ( $\lambda = 800 \text{ nm}$ ) can be verified by correlating the beam's energy spectrum with the relative timing of the beam and drive laser; the timing is randomly varied within a 50-ps window using a voice-coil-activated delay stage. An example of the iCCD image of the beam without laser is shown in Figure 2. The low-energy peak shows the population that scatters through the glass substrate and the high-energy peak shows the (smaller) population that passes through the acceleration vacuum channel of the MAP. A region-of-interest-restricted trace of the horizontal projection of the intensity is also shown in the figure. The separation between the peaks corresponds to  $\sim 300 \text{ keV}$  energy loss due to 1 mm glass substrate, which is in line with expected behaviour.

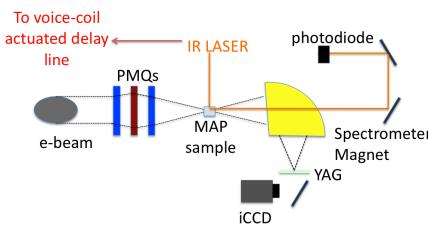


Figure 1: Schematic of the experimental setup at NLCTA.

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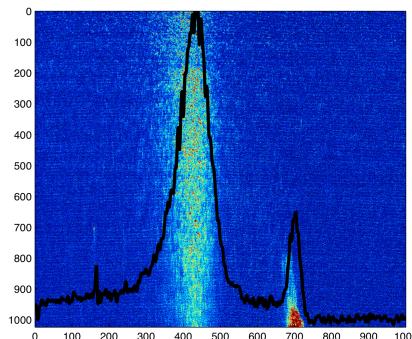


Figure 2: Sample raw camera image showing electron beam spectrum. The energy calibration is 1.2 keV/pixel. The large peak contains particles passing through the glass substrate; the smaller, higher-energy peak contains particles transmitted through the vacuum gap. The black trace shows the integrated signal with a restricted ROI.

## SIMULATION RESULTS

Modelling of the expected beam behaviour from the E163 Experimental Hall was done by combining results from the simulation codes G4Beamline and VORPAL [2]. G4beamline is used to model the scattering of a 20-μm-tall beam through the glass substrate and dielectric of the MAP; and VORPAL is used to model the acceleration of electrons that are transmitted through the 800-nm vacuum channel. Figure 3 shows the energy distribution of a 60-MeV beam, with initial energy spread of 10 keV, after 1 mm of travel through accelerating fields of two different amplitudes. As can be seen from the figure, the width of the transmitted population peak increases with increasing field, and a double-peak shape appears on the transmitted population peak.

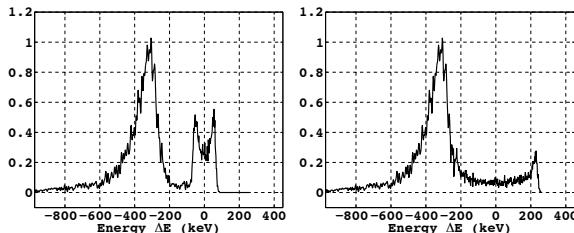


Figure 3: Computed spectrum of a 20-μm diameter electron bunch after passing through the MAP: (a) with 100 kV/mm accelerating field; (b) with 400 kV/mm accelerating field.

## DATA ANALYSIS

During experimental runs, the data acquisition system automatically records an equal number of laser-on and laser-off signals as the voice-coil actuated delay stage of IR laser is varied. The resulting data consists of spectrum for each electron beam shot (an “event”), with and without laser power. Data files consist of every event’s spectrum image and a set of recorded experimental parameters at the time of the event including laser power and voice-coil-actuator read-back. These parameters are

saved in a single data file for a user-defined number of events. A schematic diagram of data-file construction is shown in Figure 4. Extraction of each spectrum image and associated parameters are done using parser functions in MATLAB. A data visualization tool using MATLAB graphical interface (GUI) programming was developed for convenient data visualization and analysis after the experiment.

Using the GUI, we can correlate and graph experimental parameters to check the experimental parameter ranges and spot outliers of the data set in a fast and reliable way. Filtering options have been included for important parameters such as bunch charge and voice-coil delay stage location (which controls the relative timing of laser and electron beam). With the GUI one can select, mark or delete a particular event’s data points with a cursor; identify the event number of any data point; or display the spectrum for any event number. A GUI screenshot is shown in Figure 5.

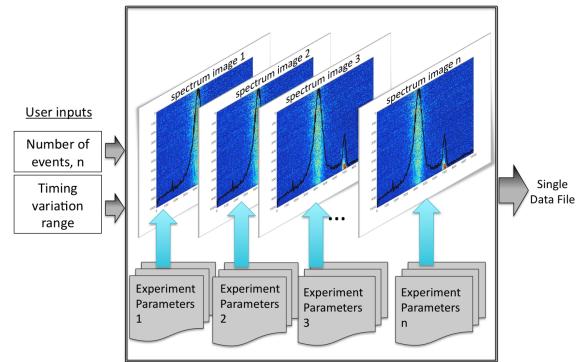


Figure 4: Data file construction schematic.

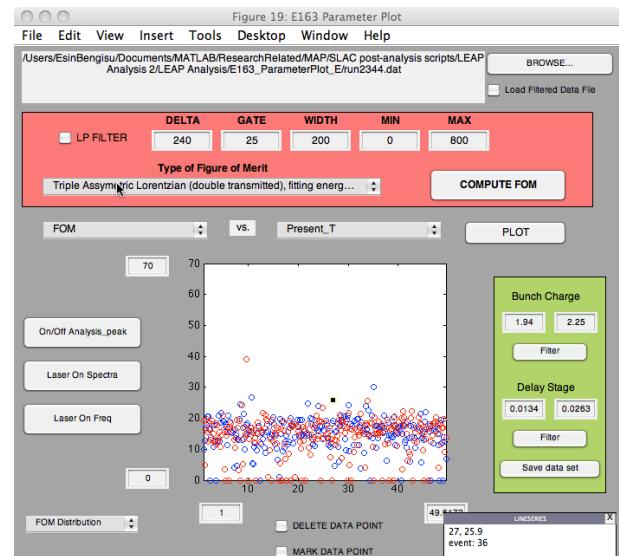


Figure 5: Screen shot of the data visualization GUI. Blue data points indicate “laser-off” events, red data points indicate “laser-on” events.

The GUI provides access to a variety of computed figures of merit (FOMs) from the spectral data, via a pull-down menu. The goal of a FOM for this experiment is to quantify the interaction of the e-beam with the laser field. This interaction is also a function of the timing of laser and the e-beam. Consequently, the relationship between the FOM and the delay stage position can be used as an indication of interaction of the electron beam with the laser field. Identification of a FOM that can quantify the interaction of the electron and laser beams is discussed using the expected experimental results generated by combined simulations of G4Beamline and VORPAL.

The simulated spectrum shows a broadening and double peak for the transmitted population, as shown in Fig. 3. The degree of broadening can be measured by fitting the transmitted-population peak to a distribution function; the fitted width becomes the FOM. Figure 6 shows several examples of fits to simulated acceleration results using a 200 kV/mm accelerating gradient, including double-Gaussian, double-Lorentzian, and triple-Lorentzian fits. Another approach is a gated-sum FOM that effectively distinguishes between transmitted peaks with flat and non-flat tops. This approach first indentifies the peak point of the transmitted population and then compares the mean amplitude of a region around the transmitted peak value to the peak value. The gated-sum FOM is most useful in the case of very high energy spreads, when the spectral peak approaches a flat-top and is no longer well represented by Gaussian or Lorentzian functions.

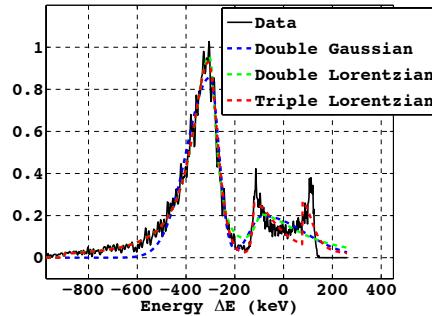


Figure 6: Simulated spectrum with examples of several different fitting functions.

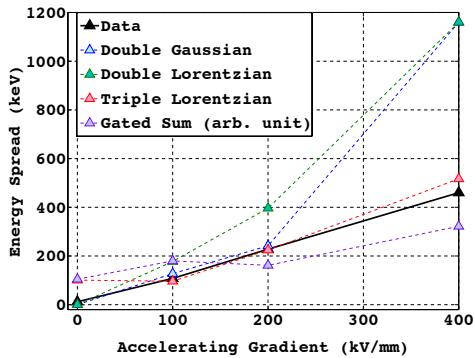


Figure 7: Comparison of different fit-based FOMs with manually measured FWHM of transmitted peak, as a function of acceleration gradient, for simulated spectra.

Using simulated spectra for a range of accelerating field gradients, a comparison of the FOMs to the manually measured FWHM of the energy spread of the transmitted population was made (Figure 7). As can be seen from this comparison the accuracy of fitting functions goes down as the accelerating gradient increases. The Triple-Lorentzian fit has the smallest error among the FOMs investigated here. A more careful analysis would require careful monitoring of all experimental parameters, with possible manipulation of fitting parameters based on experimental conditions.

## SUMMARY

Numerical simulations and data analysis of dielectric laser acceleration experiments were reviewed. A search for a reliable figure of merit based on the numerical results generated with G4Beamline and VORPAL was presented. A triple-Lorentzian fit was found to be the most successful among the automated FOM methods investigated using the simulated data.

## ACKNOWLEDGMENT

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## REFERENCES

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