

# UPGRADED PHOTONINJECTOR LASER PULSE TRAIN GENERATOR AT THE ARGONNE WAKEFIELD ACCELERATOR\*

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## Abstract

The Argonne Wakefield Accelerator (AWA) facility operates a high-charge (100s of nC) electron beam in a bunch train, with eight electron bunches at a 769 ps spacing matching the linac operating frequency of 1.3 GHz. AWA's electron beam is optimized for producing large wakefields in resonant structures to study structure wakefield acceleration. This is achieved by maximizing total beam charge, and by correct bunch train timing to enhance the wakefield via inter-bunch coherence. The properties of the bunch train are determined by a "multisplitter" in the photoinjector laser system, in which a series of beamsplitters splits one laser source into eight - ideally equal - pulses. However, AWA's previous system did not split pulses evenly, with up to a 2:1 ratio between pulse energies within a train. Damaging electrical breakdown events within the electron gun, driven by high single bunch charge, occurred at lower total charge in this non-uniform set-up, limiting maximum charge. Thus, a new multisplitter using polarizing beamsplitters and half-wave plates (HWP)s was implemented. Unlike the previous fixed-ratio beam-splitter design, the new system enables tuning the splitting ratio for each beamsplitter, resulting in a more uniform pulse train. Large 2" optics and uncoated HWP's are also used to increase the laser intensity damage threshold (LIDT). This paper presents the design, characterization and lessons learned in early commissioning of AWA's upgraded laser pulse train generator.

## INTRODUCTION

Pulse train generators have been implemented in photocathode laser systems across many accelerator facilities [1,2], and are well suited for creating pulses separated by 10s of ps to several ns. Figure 1A shows the existing AWA multisplitter (Excitech EX-PE-4OO), installed around 2015. Four non-polarizing beamsplitters are arranged in 3 delay lines to create 16 pulses, 8 of which are sent to the photocathode. The pulses are separated by 769 ps, and can be finely tuned using motorized delay stages in each delay line.

The beam splitters in the existing AWA multisplitter are not perfect 50-50 splitters, leading to different losses in each straight-ahead versus delay line. As a result, the bunches within the bunch train produced by this laser system were not uniform, and differed in charge by up to a factor of two. During high-charge operations, we observed that the higher

the single electron bunch charge within our train was, the higher the chance of dielectric breakdown within the electron gun. Thus, to maximize the overall charge in the bunch train, having an equal charge in each bunch is important.

To create a more uniform train, we designed an upgraded multisplitter using polarized beamsplitters, shown in Fig. 1B. In this design, as illustrated in Fig. 2, s-polarized light is passed into the delay line of each stage, while p-polarized light continues straight. These beam splitters are optimized for 56° reflections, thus the trapezoidal shape of the first delay stage. For the second and third delay stages, a bow-tie configuration was used instead for compactness.

## MATERIALS AND METHODS

### Placement within the AWA Laser System

The AWA laser system consists a 785 nm laser which is frequency-tripled to produce 262 nm UV light. Light from a Coherent Vitara-T oscillator is amplified by a Ti:Sapphire regenerative amplifier driven by a Spectra Physics Ascend laser system. A subsequent multipass amplifier powered by a Powerlite DLS Laser system further increases the pulse power. The pulse is compressed to 300 fs, and then undergoes frequency tripling to 262 nm. The pulse train generator, or "multisplitter," then splits the pulse into up to 8 pulses separated at 769 ps. The beam is subsequently sent through a series of  $\alpha$ -BBO crystals to stretch the pulse length to 6 ps, and a multi-lens-array homogenizer system [3] to create a smooth flat-top profile, before delivery to a Cs<sub>2</sub>Te photocathode.

### Multisplitter Construction and Alignment

We assembled the new multisplitter (Fig. 3) using polarizing beamsplitters (Eksma Optics:  $R_s > 99.5\%$ ,  $T_p = 95\% @ 262\text{nm}$ ), half-wave-plates and dielectric mirrors (Lattice Electro Optics: CWO-262-02-20-NoAR, RX-262-45-UF-2038). Large optics were used to provide 2 in aperture across the pulse train generator. Due to the dielectric mirrors having high reflectivity from 45° to normal incidence, but lower reflectivity at high angles, dielectric mirrors were used in the 2L and 4L delay lines, while additional polarizers were used in the 1L delay. We aligned and tested this set-up at  $\approx 25\%$  pulse energy (0.245 mJ). After angular adjustment of each optic, the HWP's were rotated to achieve the most uniform pulse train. Flags were used to block the beam to measure pulses sequentially on a downstream photodetector. Total transmission was 50.2%.

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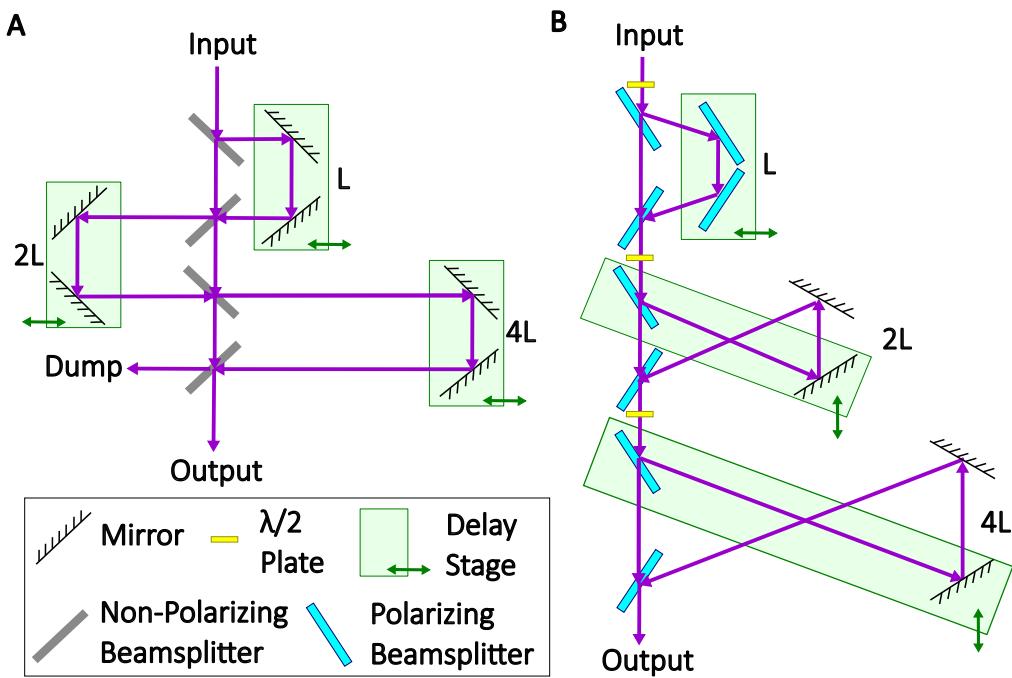


Figure 1: A) previous AWA multisplitter using half-silvered mirrors, B) new AWA multisplitter using polarizing beam splitters.

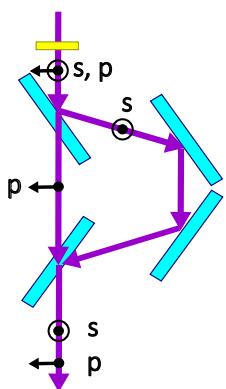


Figure 2: One stage of a polarizing beam splitter system.



Figure 3: Installed multisplitter with laser path depicted in light blue.

## RESULTS

The previous multisplitter balance (Fig. 4A), was often as bad as a 1:2 ratio between the weakest and strongest pulse.

The new multisplitter (Fig. 4B) demonstrated significantly better balance, with the weakest pulse typically 20-30% less in energy compared to the strongest pulse. However, there is still additional room for improvement.

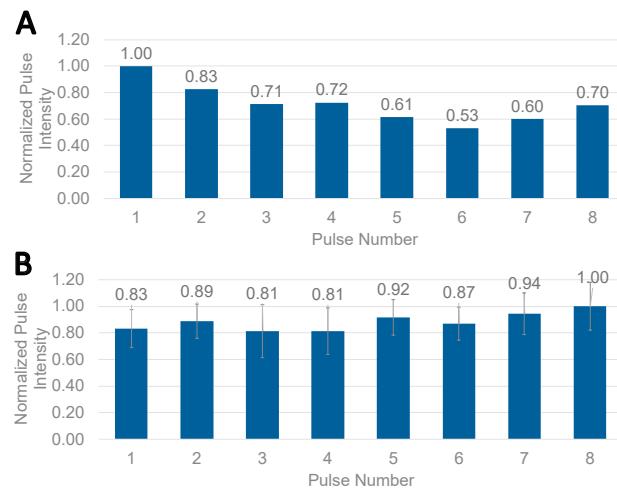


Figure 4: A) previous multisplitter balance, B) new multisplitter balance. Error bars are a  $\pm 1$  standard deviation of the mean.

## FUTURE IMPROVEMENTS

### Brewster Plate Attenuator

Upon further analysis, we realized modifications are necessary to produce a uniform bunch train using this multisplitter. Based on the properties of the polarizing plates ( $R_s > 99.5\%$ ,  $T_p = 95\%$ ) and dielectric mirrors ( $R = 99.473\%$ ), we expect 97.7% transmission of s-polarized light and 90% transmission of p-polarized light in each stage. This unequal attenuation means that the half-wave plate should favor more p-polarized light for equal splitting.

However, in 2L and 4L stages, we are sending in both p-polarized and s-polarized pulses. Thus, the input s and p pulses will be split differently, unless the half-wave-plate is tuned for equal splitting (45° rotation). Thus, we will make the loss in the delay and straight-ahead portions equal using a Brewster plate attenuator.

Figure 5 shows a Brewster plate (thin UV fused-silica glass) inserted in the delay line, with a 56° reflection pointed onto the laser table. In this orientation, s-polarized light in the delay line appears p-polarized to the Brewster plate, enabling high transmission. Rotating the Brewster plate towards normal incidence increases reflectivity, and thus attenuation. We expect this to enable variable attenuation up to  $\approx 8\%$ .

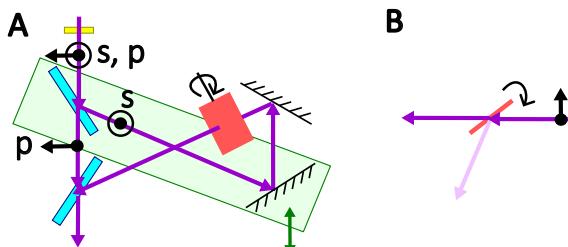


Figure 5: Brewster Plate attenuator, A) top view, B) side view.

### Laser Power Drift Compensation

Sequential measurement of laser spot power makes this measurement sensitive to laser drift, which is prominent, especially for the first 2 hr of laser operation. Future measurements can eliminate this by normalizing to the input laser power using a second photodetector, or by single-shot measurements with a fast photodiode.

### Additional Delay Stage for 16 Pulses

For future experiments that require long bunch trains, we will be adding an additional “8L” stage, with a delay length of 184.8 cm, to produce 16 pulses. Candidate cavity geometries are shown in Fig. 6. The “retroreflector” geometry shown is beneficial for its parallel laser paths and right-angle reflections, which may make creating long delay lines easier. The folded geometry is also fairly compact, but still requires a large contiguous portion of the laser table. The chosen

geometry will be dependent on what best fits in the available space of our laser system.

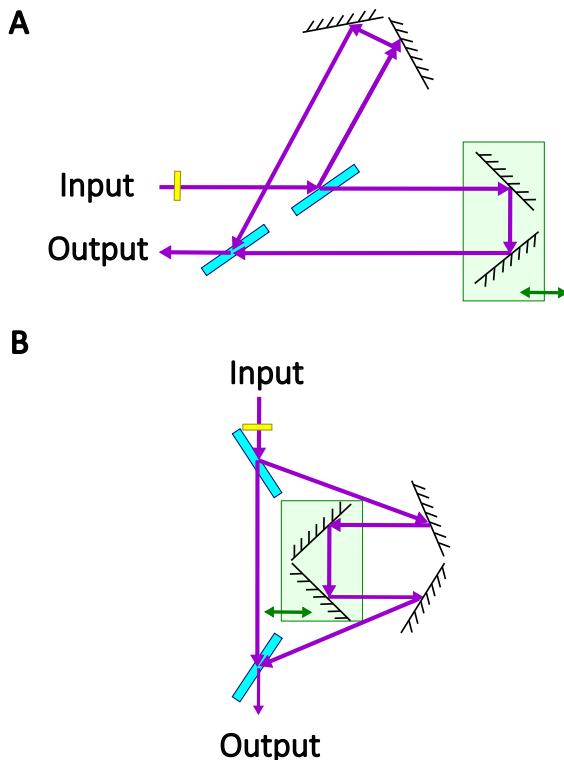


Figure 6: Cavity geometries under consideration for an 8L stage, to make 16 pulses: A) “retroreflector,” B) “folded”.

## CONCLUSION

The new multisplitter improves upon the the uniformity of the AWA pulse train significantly, but can be improved further with a variable attenuator in the delay line, and extended to longer bunch trains with one additional stage. Additional or fast detectors can also be used to improve the measurement by removing the effect of laser drift. Once the laser balance is improved, we will then deliver light from this system to the photocathode to produce electron beams, improving the quality and reliability of AWA high-charge bunch train operation.

## REFERENCES

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