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BUNCH LENGTH MEASUREMENTS USING CTR AT THE AWA WITH COMPARISON TO SIMULATION

N. Neveu[1]*, L. Spentzouris, Illinois Institute of Technology, Chicago, IL, USA
A. Halavanau, P. Piot[2], Northern Illinois University, DeKalb, IL, USA
[2] also at Fermilab, Batavia, IL, USA
S. Antipov, Euclid Techlabs LLC, Solon, OH, USA
J. G. Power, E. Wisniewski, C. Whiteford, [1]Argonne National Laboratory, Lemont, IL, USA

Abstract

In this paper we present electron bunch length measurements at the Argonne Wakefield Accelerator (AWA) photoinjector facility. The AWA accelerator has a large dynamic charge density range, with electron beam charge varying between 0.1 nC - 100 nC, and laser spot size diameter at the cathode between 0.1 mm - 18 mm. The bunch length measurements were taken at different charge densities using a metallic screen and a Michelson interferometer to perform autocorrelation scans of the corresponding coherent transition radiation (CTR). A liquid helium-cooled 4K bolometer was used to register the interferometer signal. The experimental results are compared with OPAL-T numerical simulations.

AWA FACILITY

The AWA Facility houses two rf photoinjectors, both operating at 1.3 GHz. The photoinjector used for these studies consists of a gun and solenoids followed by six accelerating cavities, as shown in Fig. 2. This beam line is capable of low (0.1 nC) and high charge (100 nC) operation. Both beamlines utilize the 248 nm UV laser to generate photoelectrons with the Full Width Half Maximum (FWHM) pulse duration ranging from 1.5 ps to 10 ps. The bunch charge is routinely adjusted depending on the requirements of the experiments downstream of the photoinjector. Typical operating charges are 1, 4, 10, and 40 nC. While these are the most common operating modes, other charges have been requested and provided depending on the experiment. Recent experiments include emittance exchange [1], structure tests [2], thermal emittance measurements [3], and two beam acceleration [4]. Recently, AWA laser system was upgraded with a microlens array (MLA) setup that yields very transversely homogeneous bunches [5]. The effect of the MLA generated beam on the final electron bunch length had not been investigated, motivating this work.

MEASUREMENT TECHNIQUE

In order to measure the bunch length, we performed an autocorrelation scan of the CTR produced by the electron distribution [6, 7]. In brief, the CTR is transported into a Michelson interferometer (MI) where it's split and directed into two MI arms with a half-transparent pellicle [8]. The CTR beams are then combined together at the exit of the MI with the variable path difference. The resulting CTR intensity is registered with a liquid helium cooled IR Labs bolometer [9] as a function of path difference. The path difference is then converted into time as $\Delta\tau = 2\Delta x$. The resulting FWHM bunch duration is determined from the Gaussian fit of the interferogram; see Fig. 1. To alleviate the effect of charge fluctuations, we recorded 15 bolometer values for each data point. The values were then averaged and the errorbars were deduced from the data. The data points outside of the 3σ bracket were considered as outliers and discarded. The resulting interference pattern as a function of time delay in the MI is similar to that presented in Fig. 1.

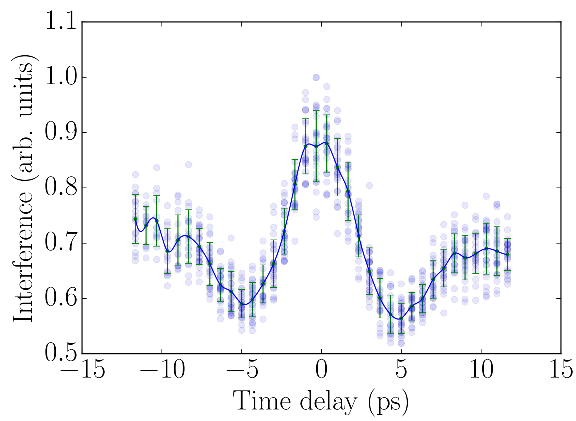

Figure 1: An example interferogram for Q=30 nC and laser pulse FWHM of 1.5 ps.

EXPERIMENTAL SETUP

The beam line layout is shown in Fig. 2. Bunches were allowed to propagate freely to the CTR screen. The only focusing elements used were solenoids S_1 and S_2. As the bunches passed the CTR screen, light was emitted through a window located next to the screen, as shown in Fig. 3. A slit was used to prevent background x-rays from reaching the bolometer. After passing the slit, the CTR propagated to the interferometer also shown in Fig. 3. A remotely movable stage inside the interferometer was swept, and the resulting combined signal fed to the bolometer. Periodic refilling of the helium was required throughout the day in order to keep the bolometer at 4 K. The bolometer sensitivity knob was at position "1" and the gain set to 200. For the case

* nneveu@anl.gov

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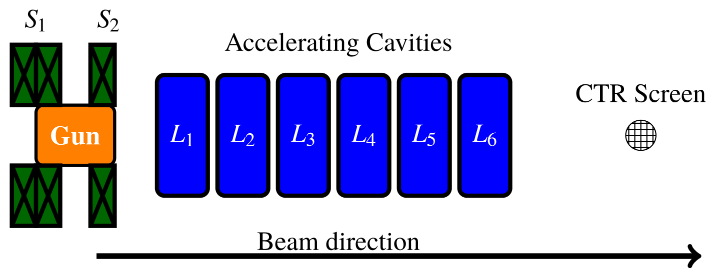

Figure 2: Beam line layout at the AWA.

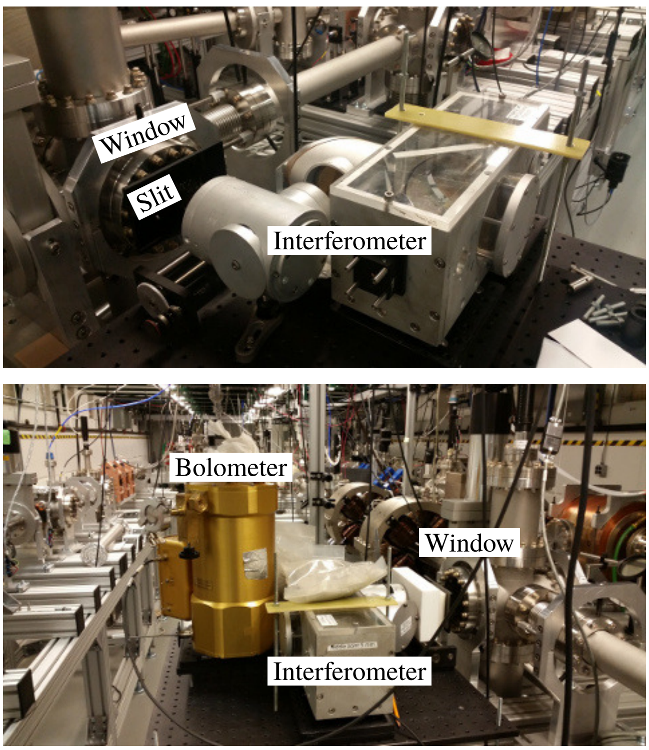

Figure 3: IR labs bolometer and MI interferometer used in the experiment to capture CTR light as it exited a window on the beam line.

of 1 nC electrons beams, the laser transverse profile was homogenized prior to the vacuum injection [5]. To produce high-charge 30 nC beams, we implemented an additional laser beamline that bypasses the homogenizer due to the losses in the MLA and relay optics.

SIMULATIONS

Simulations of the AWA beam line shown in Fig. 2 were performed with the code and OPAL [10]. The gun, accelerating cavities, and solenoids were modeled with 2D Poisson/Superfish [11] files. All field maps were in the T7 format. Input parameters for the simulations are shown in Table 1. Note that on crest refers to the phase of max energy gain. In the case of the gun, a - 5° phase is measured w.r.t the peak rf voltage.

Four scenarios were simulated, three low charge cases at 0.3, 0.7, and 1 nC, and a high charge case at 30 nC. These

Table 1: Simulation Parameters

Parameter	**Low Charge**	**High Charge**
Charge	0.3, 0.7, 1.3 nC	30 nC
Gun Gradient	65 MV/m	65 MV/m
Gun Phase	0°	−5°
S_1	230 A	500 A
S_2	150 A	235 A
Linac Phases	On crest	On crest
Laser FWHM	1.5 ps	1.5 ps
Laser Radius	2 mm	9 mm

charges and input parameters were specifically chosen to match experimental measurements that had taken place or would take place in the future. Each simulation was run with 10,000 particles on 8 cores, and ran 2.5 minutes to reach a z location of 17 m. Prior work [12] indicates the bunch length is not very sensitive to the number of particles or grid size. This would not be the case if we were comparing emittance, or transverse characteristics. We expected charge, energy, and laser parameters to have the most impact on the simulation values.

RESULTS

Comparison of simulation and experimental results are shown in Fig. 4. While, we do not have an exact match, the results follow the same trends. The discrepancies indicate there are still adjustments that can be made to the simulation model. We will continue to try to improve agreement as more of these measurements are made. This can include better measurements of the beam energy and careful attention to other beam line parameters such as the laser radius and solenoid strengths. In the case of high charge simulations, where the agreement is the worst, more consideration is needed for large charge fluctuations in the data.

Experimentally measured values of the bunch duration are shown in Table 2. Note the units in the table are picoseconds and the units in Fig. 4 are millimeters. The table gives bunch duration, and the plot gives bunch length for the same data. We hope these can serve as future reference for others doing experiments at the AWA.

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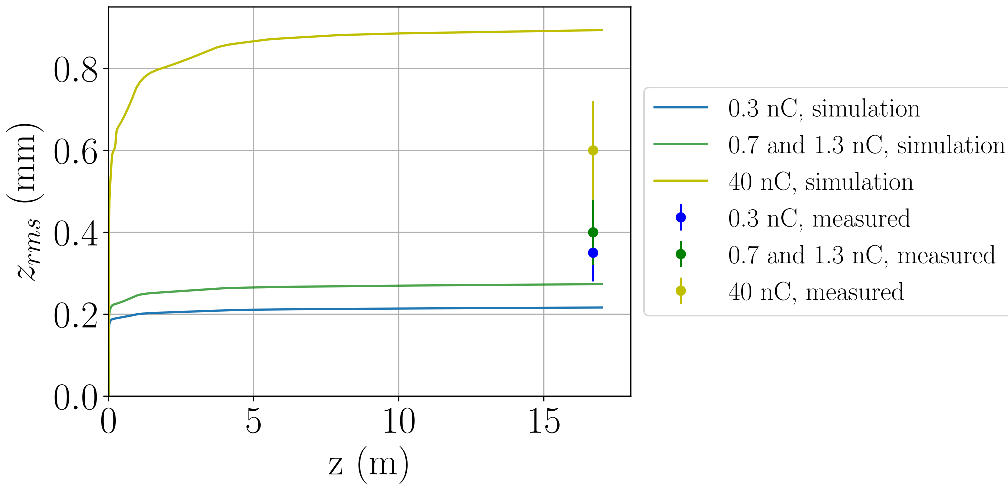

Figure 4: Comparison of simulations and experimental measurements.

Table 2: Experimental Measurements

Charge	Bunch Dur. (RMS)	Laser spot size
0.3 nC	2.2 ps	4 mm
0.7 nC	2.6 ps	4 mm
1.3 nC	2.6 ps	4 mm
30 nC	4.1 ps	9 mm

CONCLUSION

We performed experimental measurements of the electron bunch length using CTR and scanning interferometer technique. The data was analyzed and compared to OPAL simulations. The bunch length for the cases of 1 and 30 nC is reported. We note a decent agreement between the simulations and experimental results. The experimental setup will be used in the future AWA CTR studies.

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