

# HIGH CHARGE SHORT ELECTRON BUNCHES FOR WAKEFIELD ACCELERATOR STRUCTURES DEVELOPMENT\*

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## Abstract

The Argonne Wakefield Accelerator group develops accelerating structures based on dielectric loaded waveguides. We use high charge short electron bunches to excite wakefields in dielectric loaded structures, and a second (low charge) beam to probe the wakefields left behind by the drive beam. We report measurements of beam parameters and also initial results of the dielectric loaded accelerating structures. We have studied acceleration of the probe beam in these structures and we have also made measurements on the RF pulses that are generated by the drive beam. Single drive bunches, as well as multiple bunches separated by an integer number of RF periods have been used to generate the accelerating wakefields.

## 1 INTRODUCTION

In order to study and demonstrate the wakefield acceleration scheme and also the two beam acceleration concept, we have designed and constructed a facility called Argonne Wakefield Accelerator (AWA). The AWA consists of three major components: (i) a photocathode based RF electron gun capable of producing up to 100 nC (drive gun) followed by two standing wave linac sections for post acceleration, (ii) a second photocathode based RF electron gun capable of

generating low charge short electron bunches synchronized with the drive bunches (witness gun), and (iii) an experimental section for wakefield measurements, in which the witness beam is accelerated by wakefields generated by the drive beam. We have obtained electron bunches of 10 - 100 nC with FWHM of 10 - 40 ps, which have been used for initial wakefield experiments in both dielectric loaded structures [1] and plasmas [2]. These unprecedented high-charge short-electron bunches, allied with the uniqueness of having two photocathode RF guns with adjustable delay between their beams, make AWA an ideal facility for the study of electron beam driven wakefield acceleration.

## 2 AWA ELECTRON GUNS AND LINAC STRUCTURES

Figure 1 shows a schematic of the AWA layout. The half-cell drive gun was designed to have a high accelerating field (92 MV/m at the photocathode surface) to allow the extraction of high charge electron bunches, and to produce a 2 MeV beam with the limited RF power available at the design time (1.5 MW at 1.3 GHz) [3]. The high intensity of the accelerating field in the gun permits the generation and acceleration of short electron bunches, without having to rely on magnetic pulse compression. Magnesium was chosen to be the photocathode material for its ruggedness and quantum efficiency ( $5 \times 10^{-4}$ ). The 2 MeV bunches generated by the drive gun subsequently

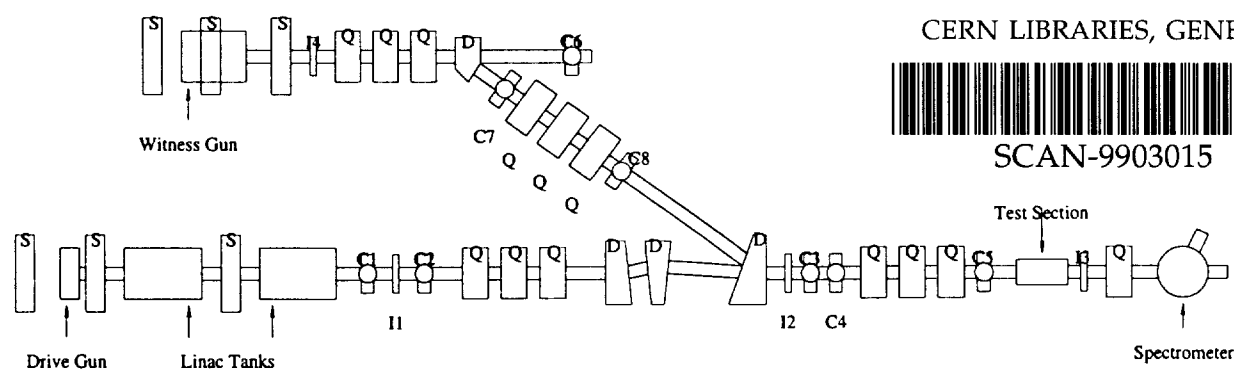


Figure 1: Schematic of the AWA experimental setup: S, Q, and D indicate solenoids, quadrupoles, and dipoles, respectively; the four integrating current transformers are labeled I1 through I4; the eight diagnostic ports are labeled C1 through C8.

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pass through two standing-wave,  $\pi/2$  mode linac tanks (shunt impedance of 21.5 M $\Omega$ /m), increasing the beam energy to about 14 MeV. The linac structures have large irises (10.16 cm diameter) to minimize the generation of wakefields by the propagation of the high charge drive bunches [4]. The beam is then focused by quadrupoles and bent by three dipoles to allow for the injection of both the drive beam and the witness beam into the wakefield experimental section. The witness gun [5] is a 6-cell standing-wave  $\pi/2$  mode structure that generates 4 MeV bunches of 300 pC. Its photocathode material is copper. The witness beam goes through combining optics and then through the wakefield device (plasma or dielectric structure) trailing the drive beam, thereby probing the wakefields excited by the drive bunches. Energy changes of the witness beam are measured by a spectrometer magnet located downstream of the wakefield experimental section.

The two RF guns and the two linac structures are powered by a single klystron (Thomson TH2022D; 24 MW, 4  $\mu$ s pulses), via necessary power splitters and phase shifters. The laser system is comprised of a dye oscillator (496 nm) pumped by a tripled YAG, which is then followed by a dye amplifier, a doubling crystal and finally an excimer amplifier. This laser is capable of producing up to 8 mJ with 6 ps FWHM at 248 nm. The laser beam is then split and a small fraction of it ( $\sim$  15%) sent to the witness gun. There is an adjustable delay between the drive gun and the witness gun laser beams. This allows us to vary the delay between the drive and the witness electron bunches (obviously the RF phases have to be adjusted accordingly, in order to maintain the same launching phase).

### 3 DIAGNOSTICS AND BEAM CHARACTERIZATION

There are four integrating current transformers (Bergoz ICT - 082-070-20:1) installed on the beamlines to measure bunch charge at various locations as indicated in Fig. 1. Bunch length measurements [6] are performed using radiation emitted by the electron beam as it passes through a Cerenkov radiator. The Cerenkov light is sent to a Hamamatsu M1952/C1587 streak camera for pulse length measurements. Insertable quartz or aerogel plates are used as Cerenkov radiators. The aerogels require a more elaborate holder than the quartz plates, but offer several advantages. The aerogels need to be in a vacuum-tight holder which is inserted in the beam path. The electron beam enters our holder through a thin aluminum window (0.15 mm). It then traverses the aerogel (under atmospheric pressure) and emits Cerenkov radiation, which leaves the aerogel holder through a quartz window. Our aerogels have an index of refraction of 1.009, therefore the Cerenkov light is emitted at an angle of 7.4 $^\circ$  with respect to the direction of propagation of the 14

MeV electrons. The light is then reflected by a mirror and leaves the vacuum chamber through a diagnostic view port.

Figure 2 shows measurements of pulse length as a function of bunch charge. In these plots the charge was measured by the integrating current transformer I1 (see Fig. 1), and the bunch length was measured using the aerogel radiator and the streak camera. In Fig. 2a we show a detailed charge scan in the range 15 - 35 nC and the corresponding FWHM of the pulses; many pulses were measured in this range and then binned in groups of 51. The plot shows the average value of charge and bunch length for seven bins, indicating that in this charge range the pulse length is almost constant, fluctuating between 15 and 20 ps. The plot in Fig. 2b shows a charge scan over a much wider range, but each point in this graph is the average of only three pulses. We have plotted the FWHM of the bunch lengths and also the 95% RMS values (this was calculated taking into account only the section of the pulse profile with intensity within 95% of the peak value, with the purpose of discarding the effect of the small background noise at the wings of the distribution). The ratio between the 95% RMS and the FWHM values shows that the pulses are not gaussian. The large fluctuation in the FWHM of the pulses also shows that the detailed shape of the temporal profile varies considerably from pulse to pulse. In all of these bunch length measurements the changes in bunch charge are accomplished by varying the laser pulse energy (either by purposely attenuating the laser beam, or due to

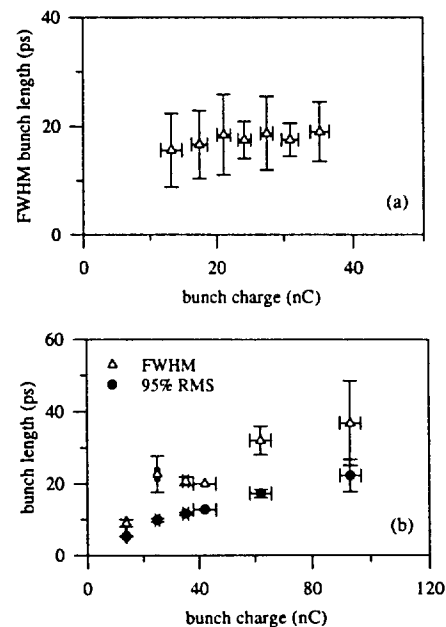


Figure 2: Measurements of electron bunch length as a function of bunch charge: (a) detailed pulse length measurement in the 15 - 35 nC range; (b) measurement over a wider range of charges, each point represents the average of three pulses.

the natural fluctuations in the laser power); when the change in the emitted bunch charge is large, it becomes necessary to readjust the solenoids and RF phases to compensate for the changes in the space charge forces.

#### 4 WAKEFIELD MEASUREMENTS

We can map out the wakefields in a dielectric loaded structure by varying the delay between the drive bunch and the probe (witness) bunch. By measuring the change in energy of the witness beam, we obtain a direct measurement of the wake potential. This detailed mapping of the wakefields [1] was performed in a structure consisting of a hollow borosilicate glass cylinder ( $\epsilon \sim 4$ ) with inner radius of 5.0 mm and outer radius of 7.7 mm. Figure 3 shows the wake potential as measured from the energy change of the centroid of the witness beam as a function of the delay between the two bunches. The largest energy shift of the centroid is about 2.5 MeV/m (for drive bunches of 11 nC). Because the 2.5 mm FWHM length of the witness beam is a significant fraction of the wavelength of the wakefield (in this specific case the wakefield has an RF frequency of 15 GHz), the actual gradient is larger than the gradient measured from the witness beam centroid change in energy. By comparing the data with numerical simulations convolved with a Gaussian witness bunch shape, a true gradient of 3.6 MeV/m is inferred. Additional optimization of the laser injection phase and beamline magnet settings resulted in a gradient of approximately 6 MeV/m with a 20 nC drive beam intensity.

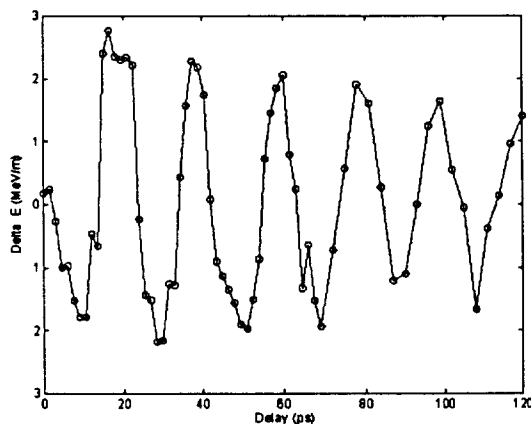


Figure 3: Wake potential measurement for a 15 GHz dielectric structure. Each data point is the change in the bend view centroid of the witness beam at the spectrometer 60° port.

#### 5 DIELECTRIC WAKEFIELD TRANSFORMER

There are advantages in building a dielectric wakefield accelerator with two separate dielectric structures, in a

transformer configuration. The drive beam generates an RF pulse as it passes through one of the structures. This RF pulse is coupled to the second dielectric structure (via a waveguide) where the witness beam is accelerated. The second tube has the same fundamental frequency but lower group velocity and transverse dimensions, thus providing an accelerating field step-up by compressing the RF pulse. Multiple drive bunches can be used, spaced by an integral multiple of the RF period, to provide a long accelerating pulse. Another advantage of having two separate dielectric structures is that the drive structure can be designed with sufficiently low transverse impedance to avoid beam breakup problems.

We have recently been designing and building dielectric wakefield transformers [7] operating at 7.8 GHz and also at 15.6 GHz. We have also succeeded in generating multiple drive bunches, by optically splitting and appropriately delaying the laser pulse to the drive gun. Figure 4 shows the envelope of the RF macropulse generated by a bunch train consisting of 4 bunches separated by 3.077  $\mu$ s.

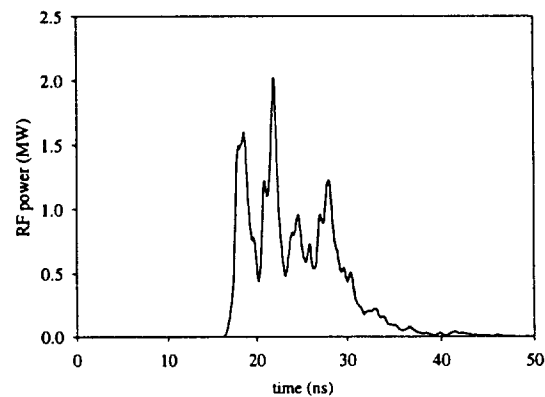


Figure 4: RF macropulse envelope for train of four drive bunches in a 7.8 GHz structure.

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