Streak Camera Measurements of Electron Bunch Length from a Copper Photocathode in an RF Gun*

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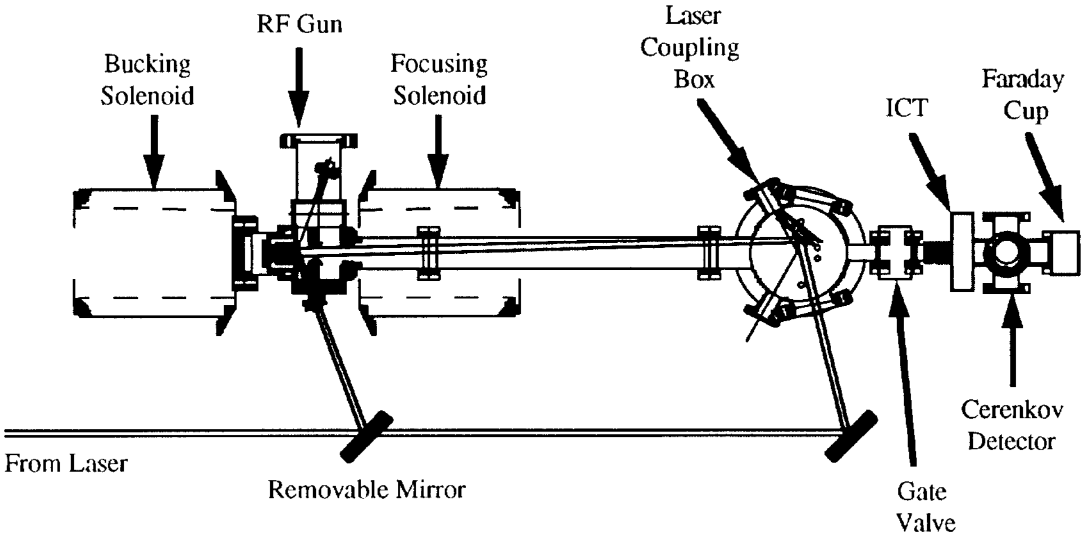

Figure 1: Diagram of the experimental setup

Abstract

Short laser pulses (sub 2 ps) of UV (λ=266 nm) light with 200 μJ/pulse. are used to produce electrons from a copper cathode in a rf gun. The electron bunch length is measured by streaking the Cerenkov radiation (λ=530 nm) from a thin (250 μm) fused silica etalon. Streaks for both 0° and 70° laser incidence angles with respect to the cathode normal are presented with a temporal resolution of 3.6 ps. The shortest electron bunch length measured was 9 ps.

I. INTRODUCTION

Although photoemission is a prompt process down to sub picosecond time scales, the production of very short (< 2 ps) electron beams from a photocathode rf gun cannot be taken for granted. Photocathode rf guns are constructed to minimized bunch length growth by allowing the creation of the electron bunch in high electric fields (up to 100MV/m). Under these fields the electrons are accelerated to relativistic velocities in less than one centimeter. Most of the bunch length growth occurs before the beam becomes relativistic and before the beam exits the rf gun.

The electron bunch length is measured using a Cerenkov radiator viewed by a streak camera. The radiator is placed as close to the exit of the rf gun as possible given physical constraints. Only a solenoid is used to transport the beam to the radiator. The streak measurements presented indicate typical electron bunch lengths of about 15 ps.

II. EXPERIMENTAL SETUP

The photoinjector consists of a Cu photocathode placed at the endwall of the 1/2 cell in a 1 1/2 cell rf gun. After completion of the measurements the electric field ratio between the 1/2 cell and the full cell was measured to be 1:1.8. This limits the maximum electric field at the cathode to less than 50 MV/m and the electron energy to 3.5 MeV. Electrons are created by a laser pulse incident on the photocathode at either 2° or 70°. The experimental setup is shown in Figure 1.

For single photon photoemission, the photon energy must exceed the work function of Cu (4.65 eV)[1]. The photoinjector drive laser was designed to produce < 2 ps laser pulses at 266 nm (4.66 eV) with up to 200 μJ/pulse. This is accomplished using chirped pulse amplification and compression of a mode-locked YAG laser (λ=1.064 μm) and frequency upconverting using two KD*P doubling crystals.

A 250 μm thick fused silica etalon served as the Cerenkov radiator. The etalon side where the electron beam entered was sanded forming a diffuse surface to prevent bunch lengthening due to multiple reflections Furthermore, the beam entrance side of the etalon was covered with a 0.005" thick aluminum foil which provides grounding of the Cerenkov radiator and

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prevents any scattered laser light from entering the field of view of the Cerenkov light. The etalon was attached on a mount which was externally rotatable about an axis perpendicular to the beam. For a relativistic electron beam, the angle of Cerenkov radiation with respect to the beam axis is

$$\theta_c = \cos^{-1}\left(\frac{1}{n}\right),$$

where n is the index of refraction of the medium. For fused silica n =1.46 and therefore $\theta_c = 47°$. The Cerenkov radiator setup is depicted in Figure 2.

This Cerenkov radiator allows 1 ps time resolution. The limiting factor in the bunch length measurements is the streak camera. We used a Hadland Imacon 500 streak camera. At the fastest sweep speed of 20 ps/mm, the time resolution is no better than 3.5 ps.

The streak camera cannot be installed directly viewing the Cerenkov detector because of the high levels of radiation inside the lead shielding. Therefore the Cerenkov light is transported through a maze in the lead shielding. Because the light intensity levels are near the detection limits of the streak camera, the Cerenkov image is reduced by a factor of 4 when focused on the streak camera slit. To achieve 3.5 ps resolution, a 25 μm slit is used at the entrance to the streak camera. Accounting for the 400% reduction in image size, the 25 μm slit infers a 100 μm acceptance at the Cerenkov radiator. The maximum time delay possible between any two Cerenkov photons created by an infinitely small thin electron beam is 1 ps. When combined with the resolution of the streak camera, the overall resolution of the Cerenkov streak system is 3.6 ps.

The streak camera resolution was verified by streaking the laser pulses. This steak camera cathode is sensitive to green 532 nm light but not to UV 266 nm light. Therefore, the

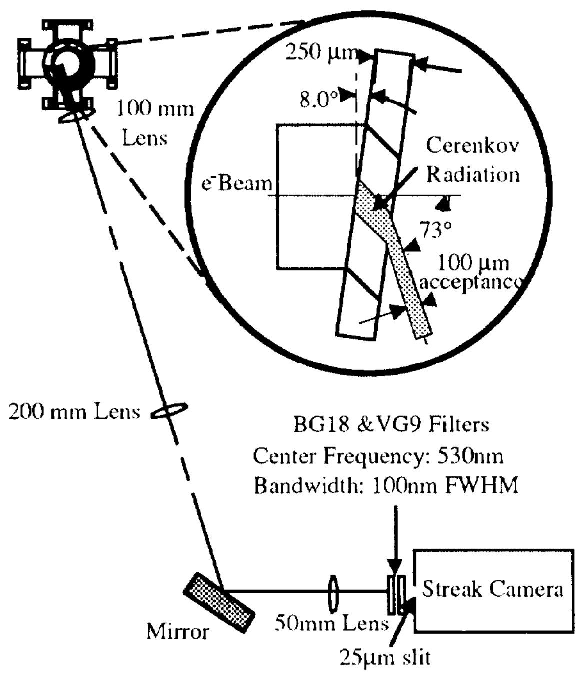

Figure 2: Cerenkov detector setup

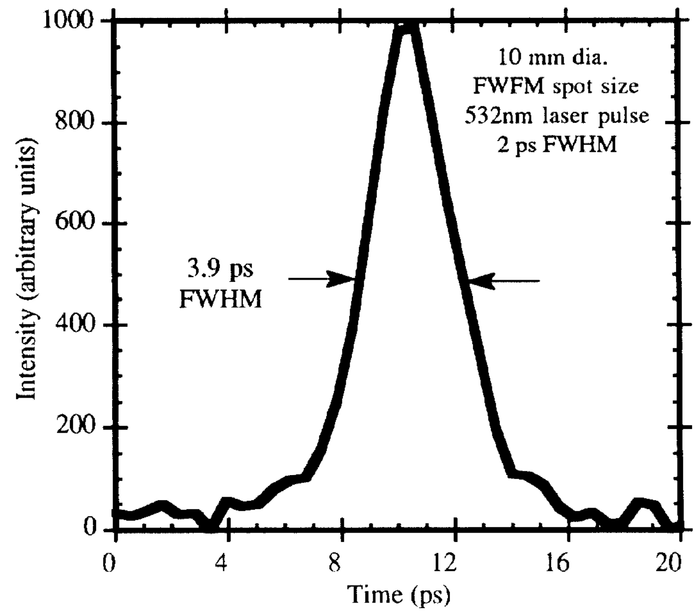

Figure 3: Laser streak indicating streak camera resolution

laser pulses were streaked after the first doubling crystal. A √2 reduction in pulse width should occur when the green light is doubled to UV. In streaking short pulses, care is taken to avoid space charge saturation within the streak camera which can result in erroneous measurements. Figure 3 depicts a typical laser streak and its corresponding integrated intensity plot.

The laser pulse streak resulted in a pulse width of 3.9 ps FWHM. Since the resolution of the streak camera is 3.5 ps, the actual laser pulse width is 1.7 ps. Autocorrelation measurements of the CW mode-locked YAG laser beam result in pulse widths of 2 ps FWHM. After doubling to green light, the pulse width is expected to decrease by √2, producing 1.4 ps pulses in reasonable agreement with the streak camera measurements.

III. EXPERIMENTAL RESULTS

The streak images appear spotted due to the low light levels incident on the streak camera. Low light levels are required to avoid space charge lengthening in the streak camera and to achieve 3.5 ps resolution. In analyzing Cerenkov streaks, the images are integrated along the space axis to provide better statistics. Each array element corresponds to .56 ps. Since the Cerenkov streak system resolution is 3.6 ps, a smoothing algorithm is used to average over the 6 nearest neighbors in the integrated array.

The first streak measurements were taken with 70° laser injection. Laser injection at 70° produces bunch lengthening from a time delay across the cathode as the laser wavefront strikes it. This produces an electron beam with a linear space time correlation. This correlation is present in the Cerenkov streak shown in Figure 4. A laser spot size of 2 mm produces a time delay of

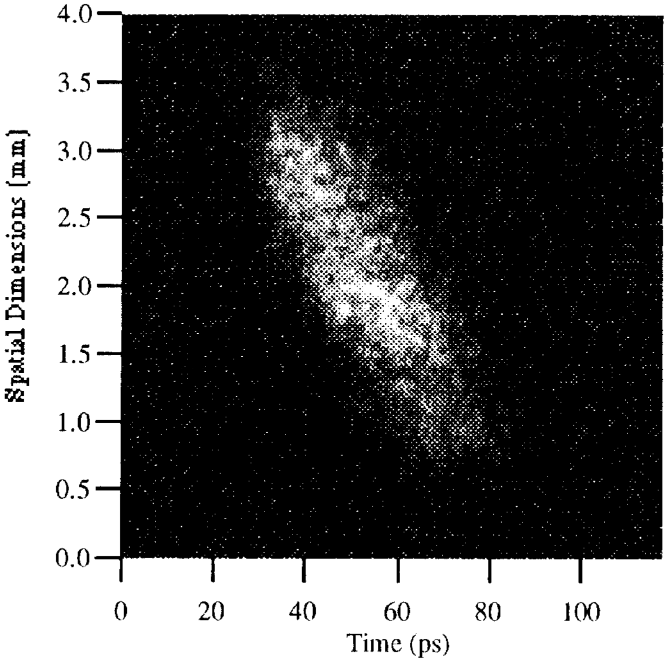

Figure 4: Electron beam streak with 70° laser injection

$$\tau \approx \frac{2\text{mm}}{c\cos(70°)} \approx 20\text{ps}$$

The measured delay from the streak in Figure 4 was 25 ps. When the streak is corrected for the delay across the wavefront, the measured pulse width becomes 13 ps.

At 2° injection, the time delay across the cathode is insignificant and the Cerenkov streaks indicate the electron bunch length directly. By focusing the laser spot to 2 mm, we were able to move the laser spot to an undamaged portion of the cathode. A streak from the undamaged cathode is depicted in Figure 5. Streaks from the damaged portion of the cathode resulted in slightly longer bunches due to an elongated tail.

Bunch length measurements with the Cerenkov radiator and streak camera resulted in 9 ps to 15 ps FWHM for various charge levels from .2 nC to 2.6 nC, however, no correlation was found between the bunch length and the charge output from the rf gun.

IV. DISCUSSION

All the streak camera measurements indicate electron bunch lengths longer than 8 ps. Measurements for 2° incidence on the undamaged portion of the cathode provide the shortest bunch length measurements averaging 12 ps. However, the 2° measurements from damaged parts of the cathode clearly characterize longer bunches with more time structure and long tails. These measurements contradict the assumption that electron bunches will mimic the laser pulses in time.

One source for bunch lengthening is space charge. The quantum efficiency data indicated significant reductions in charge production due to space charge[2]. Microemitters can further aggravate this problem possibly accounting for pulse

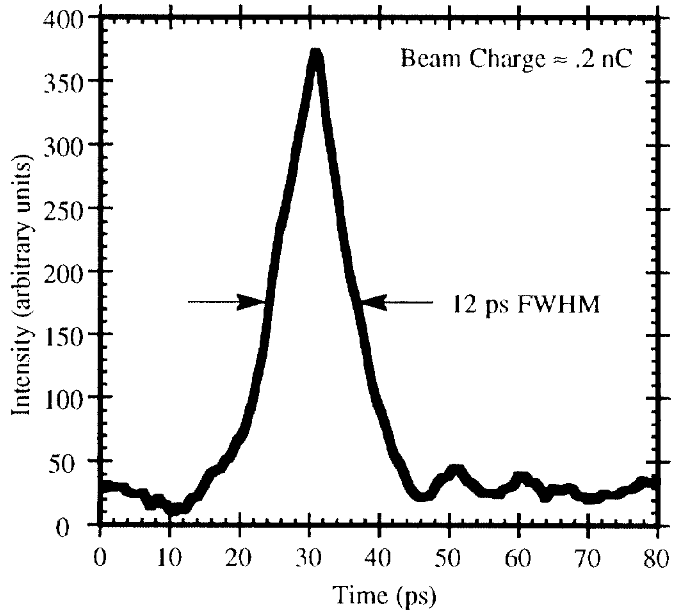

Figure 5: Electron beam streak for 2° laser injection on the undamaged part of the cathode

lengthening and time structure of the streaks from damaged portions of the cathode. PARMELA[3] simulations were performed for various output bunch charge levels from 100 pC to 1.3 nC. These simulations show a bunch lengthening as output charge is increased. For typical charge levels between .4 nC and 1.0 nC PARMELA predicts bunch lengths from 9 ps to 15 ps. These bunch lengths predictions are within the scatter of the measured bunch lengths, however, the measurements did not indicate a correlation with charge level.

V. CONCLUSION

In the present experiments, the electron bunch length does not mimic the laser pulse length. The shortest Cerenkov streak measurements indicate 9 ps bunch lengths. The physical mechanism for this bunch lengthening is under investigation. PARMELA simulations showed that bunch lengthening on the order of 10 ps can occur due to space charge, although, the bunch length measurements did not show a correlation between bunch length and charge output from the gun. However, even with the bunch lengthening, beam currents of 100 A are produced.

VI. REFERENCES

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[2]P. Davis *et al*, these proceedings
[3]K.T. McDonald,"Design of the laser-driven rf electron gun for the BNL Accelerator Test Facility,"*IEEE Trans.Electron Devices*, ED-35, 2052(1988)