COMMISIONING OF A STREAK CAMERA FOR LASER CHARACTERIZATION AT NML*

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Abstract

A streak camera will be used for longitudinal profile measurements of a drive laser for the superconducting radio frequency linac test facility at Fermilab. We are evaluating both a Photek intensified CCD camera and a Hamamatsu cooled CCD camera as readout camera options for the Hamamatsu C5680 streak camera with a synchroscan sweep unit. Trade offs on low signal sensitivity and spatial resolution for the two lens-coupled options are being evaluated. In addition, an ultrashort laser pulse from a Ti:sapphire laser is used to measure the temporal resolution of the streak system for both configurations.

INTRODUCTION

A superconducting RF accelerator test facility is currently being constructed at Fermilab. The existing New Muon Lab (NML) building is being converted for this facility. The accelerator will consist of a photoinjector, two booster cavities, beam acceleration section consisting of 3 ILC-type cryomodules, multiple downstream beam lines with various diagnostics to conduct beam tests, and a high power beam dump[1, 2]. To achieve a high quality beam for advanced accelerator R&D it is important to maintain a stable driver laser in terms of both intensity and timing.

The longitudinal properties from the driver laser are very critical to photoinjector performance. In this paper we will report the effort to study the longitudinal properties of various laser pulse with different wavelength use a Photek intensified CCD camera and a Hamamatsu cooled CCD camera as the readout camera option for the Hamamatsu C5680 streak camera unit with a synchroscan sweep unit. Streak range calibration was done using either a standard Etalon device or Colby delay box. We will also discuss trade on low signal sensitivity and spatial resolution for the two lens-coupled options. Finally we will report measurement the temporal resolution of the streak camera using an ultrashort laser pulse from a Ti:sapphire laser.

EXPERIMENTS

Laser Set up

The NML driver laser consists of a seed laser based on an ytterbium doped fiber laser system, several diode-laser-pumped amplifying stages and a non-linear optical conversion stage to convert the infrared(IR) pulses to ultraviolet(UV) pulses. In addition to the drive laser there's a possible femto-second Ti:sapphire from spectra-physics with spitfire amplifying system. A dazzler device is also put into the spitfire system to be able to do the longitudinal shaping of the amplifying pulse. A frequency trippler is build to convert the IR to UV after the spitfire. A schematic view of the possible laser layout is shown at Fig. 1.

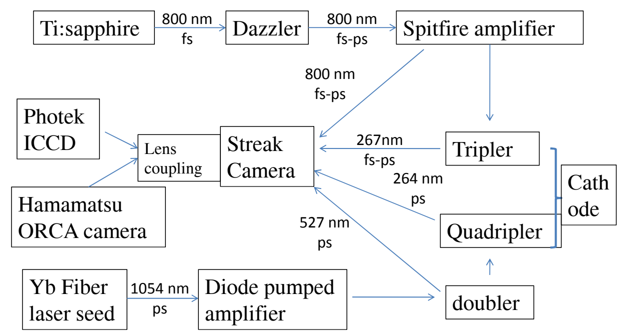

Figure 1: Schematic of newly designed laser system and longitudinal bunch length monitor with streak camera for superconductor cavity test facility in Fermi lab.

Set up and Initial Calibration

The streak camera used in this study is Hamamatsu C5680 main frame configured with M5676 synchroscan unit, M5679 dual time base extender unit and C6878 high-stability delay unit. M5676 synchroscan module is tuned to 81.25MHz with a trigger jitter of less than 1.5 ps and C6878 phase locked delay unit stabilized the camera phase over hours. In this study the output of the streak is lens-coupled to 2 different readout cameras. One is an ORCA-R2 digital CCD camera from Hamamatsu with an effective number of pixels of 1344(H)X1024(V). The other one is an intensified CCD camera from Photek with an effective number of pixels of 632(H)X480(V). Both cameras are using IEEE 1394 interface. The camera is controlled using activeDcam with MATLAB graphic user interface.

The first step to commissioning the streak camera is to determine the resolution of the streak camera. Two independent methods are applied in this study. The first method is the application of etalon with different spacing between the reflecting surfaces which leads to multiple streak images spaced at a known separation in time. A calibrated 10 ps etalon loaned from Hamamatsu Inc is inserted in front of the streak camera to calibrate for synchroscan range 1 and 2. A typical image using ORCA readout camera at

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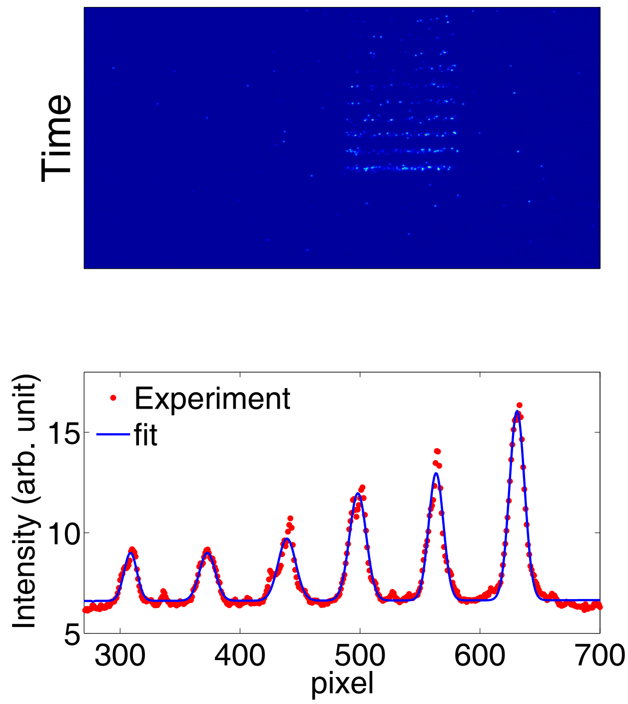

Figure 2: Top is the etalon calibration image from the streak camera with ORCA readout camera for Range 1. Bottom is the corresponding projection along the time axis (red dots) with gaussian fit (blue line).

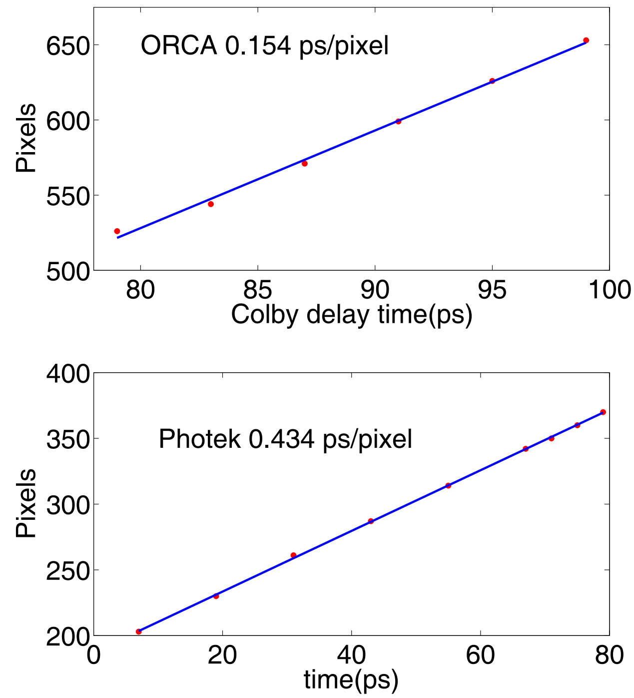

Figure 3: Top is the streak range 1 calibration using ORCA readout camera based on laser phase change using Colby delay box. Bottom is streak range 1 calibration using Photek ICCD camera.

synchroscan range 1 is shown at the top of Fig. 2. With a careful alignment we are able to get almost 10 peaks in the streak camera images. The corresponding projecting of the six strongest peaks along the time axis is plotted at the bottom of Fig. 2 with gaussian fit. The fitting gave us a calibration of 155 fs per pixel for range 1 using this configuration. 20-ps and 50-ps etalon pieces are used for the calibration of slower deflecting range of the streak camera. Corresponding results are shown in Table 1.

The second method used in this study uses a Colby delay box. The input of the Colby delay box is connected to the 81.25 MHz RF signal and the output is connected to the laser phase lock loop input. Thus by changing the delay the laser phase will also change the same amount. Top of the Figure 3 is the calibration curve with the ORCA camera at synchroscan range 1 . The result is 0.154 ps/pixel, very close to the number shown in Table 1 at the same synchroscan range. The calibration curve using the Photek camera is shown at the bottom of Figure 3. The difference of the calibration factor is just due to the difference of the vertical pixel numbers in both cameras's sensors.

Table 1: Calibration using Etalon Device for Different Synchroscan Ranges with ORCA Readout Camera

Range	**1**	**2**	**3**	**4**
Calibration (ps/pixel)	0.155	0.48	0.98	1.95

Experiment Data and Discussions

One of the important step in operating the streak camera is to determine the static spread function contribution to temporal resolution. This is the vertical beam spot size of the entrance slit mapped through the imaging system when in camera focus mode. The major contribution is the slit width itself if the slit width values are larger than 30 μm or so. On the other hand signal will be too weak if slit width is set too small. In this study the slit width is set to be 25 μm to balance these two effects.

In Fig. 4 we show projection data along the time axis from a typical focus image (red circle with blue curve as the gaussian fit) using ORCA camera and 800 nm fs laser pulse at 1kHz. We also showed the projection curve from the synchroscan range 1 image taken under the same condition in the Figure (red diamond with black curve). The synchroscan projection is apparently broader than the focus one. This is because that spatial spread of the slit image is only the static part of the camera resolution. There's is also additional dynamic part of the camera resolution term which includes energy (velocity) distribution of the photoelectrons and travel time spread caused by the deflecting field[4]. Since our tested laser pulse is less than 100

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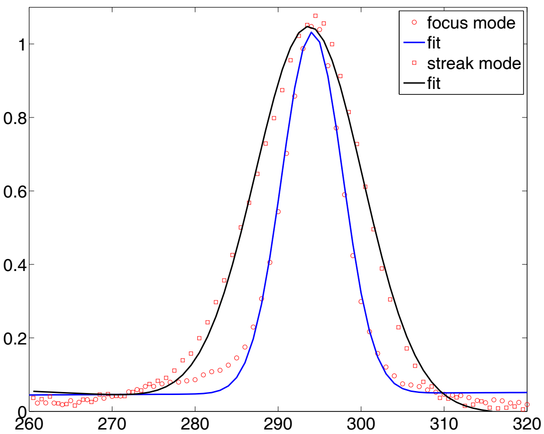

Figure 4: Projections along the time axis from both focus (red circle) and streak image (red square) taken with ORCA readout camera using ultrafast laser pulse (50 fs RMS). The blue and black curves are the corresponding gaussian fit.

fs FWHM (verified with frequency-resolved-optical-gate (FROG) method), we can take the FWHM number measured using synchroscan range 1 as our temporal resolution of the streak tube. Then we can calculate the bunch length using the following formula:

$$t_{bunch} = \sqrt{t_{obs}^2 - t_{res}^2} \tag{1}$$

where t_{bunch},t_{obs},t_{res} represents the real bunch length, measured bunch length with streak camera and streak camera resolution term respectively.

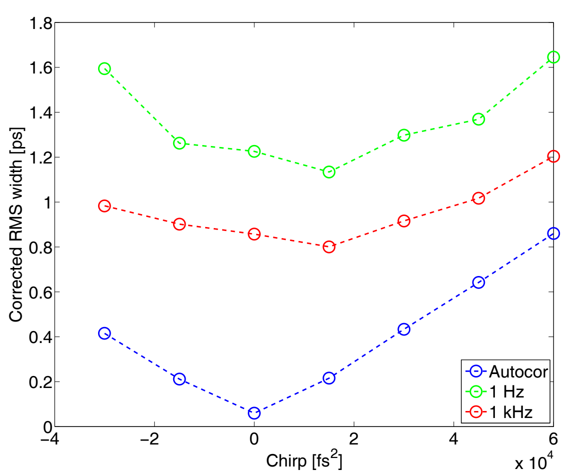

Figure 5: Bunch length measurement with ORCA read out camera using 1Hz pulse (green circle) and 1kHz pulse (red circle) with different chirp settings. Bunch length is calculated by subtracting focus image width in quadrature. The blue circle is the corresponding bunch length measured with auto-correlation method.

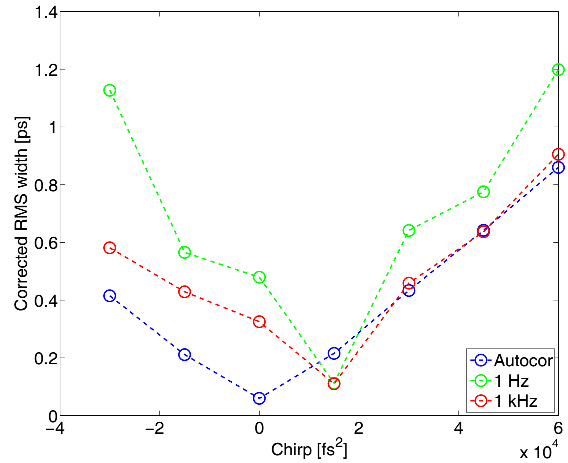

Figure 6: Bunch length measurement with ORCA read out camera using 1Hz pulse (green circle) and 1kHz pulse (red circle) with different chirp settings. Bunch length is deducted after subtracting streak camera resolution limit in quadrature. The blue circle is the corresponding bunch length measured with auto-correlation method.

In our study we changed the bunch length by changing the chirp of the bunch using DAZZLER device inside the regeneration amplifier system. Then we measured the bunch length using both FROG method and streak camera. In Figure 5 we showed the bunch length measured with FROG (blue circle) and with streak camera using 2 different repetition rates, 1Hz pulse (green circle) and 1kHz pulse (red circle). In this calculation we used just the static part of the camera resolution, i.e., spatial spread of the focus image, as our camera resolution to deduce the bunch length using equation 1. From the figure we know the corrected value using streak camera does not agree with the value measured with FROG. It is also worth to mention that the pulse length measured using 1kHz repetition rate is lower than using 1Hz repetition rates. We attribute this increase to the space charge effect on the photoelectron's energy spread with the low repetition rate. In Figure 6 we showed the same measurement data with the measured camera resolution used in equation 1. The agreement between the streak camera data and FROG data is much better. The difference between 1kHz and 1Hz laser pulse is still very obvious due to the space charge. The slight shift between the streak camera data using 1kHz pulse and FROG data is due to the different ND filter used in both setup, which introduced additional chirp on the fs bunch.

SUMMARY

In summary we successfully commissioned both a Photek intensified CCD camera and a Hamamatsu cooled CCD camera as the readout camera option for the Hamamatsu C5680 streak camera unit with a synchroscan sweep unit. That will be used for longitudinal profile measurement of a drive laser for the superconducting radio frequency photoinjector test facility at Fermilab. An ultrashort laser pulse from a Ti:sapphire laser is used to measure the temporal resolution for the streak camera. The bunch length measurement for pulses with different chirp using streak camera did agree with the measurement from our FROG measurement.

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