CORRELATING PULSES FROM TWO SPITFIRE, 800NM LASERS*

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Abstract

The E163 laser acceleration experiments conducted at SLAC have stringent requirements on the temporal properties of two regeneratively amplified, 800nm, Spitfire laser systems. To determine the magnitude and cause of timing instabilities between the two Ti:Sapphire amplifiers, we pass the two beams through a cross-correlator and focus the combined beam onto a Hamamatsu G1117 photodiode. The photodiode has a bandgap such that single photon processes are suppressed and only the second order, two-photon process produces an observable response. The response is proportional to the square of the intensity. The diode is also useful as a diagnostic to determine the optimal configuration of the compression cavity.

INTRODUCTION

The E-163 experiment studies the acceleration of electrons with optical photons. Electron production and acceleration are performed with separate lasers. The maximum acceptable RMS relative timing jitter between the lasers is the full width at half maximum (FWHM) of the laser pulses. To measure the RMS timing jitter between the lasers, a method using cross-correlation and two-photon conductivity (TPC) has been developed.

TPC has been demonstrated in commercially available diffused-junction semiconductor photodiodes. When incident light satisfies the condition $2h\nu > E_g > h\nu$ where E_g is the band-gap energy and $h\nu$ is the photon energy, TPC can be observed. When these conditions are met, the photocurrent is proportional to the square of the intensity.[1]

EXPERIMENTAL SETUP

Ultra-short lasers pulses are produced by two Spitfire, regeneratively-amplified, pulse lasers. The lasers are capable of producing sub-picosecond pulses in the 700-1000nm range. The gain medium is Ti:Sapphire. Laser 1 is pumped with an Evolution, 527nm, diode pumped, Q-switched, intra-cavity doubled, ND:YLF laser. Laser 2 is pumped with a Merlin, 527nm, flashlamp pumped, intra-cavity doubled, ND:YLF laser. Lasers 1 and 2 are triggered by both a 600Hz reference locked to 60Hz and a 79.3MHz reference also locked to 60 Hz. The seed is injected into the laser cavity on the first zero crossing of the 79.3 MHz reference following a pulse from the 600 Hz reference.

Both Spitfires are seeded by the same laser oscillator, a Tsunami, 800nm, Ti:Sapphire, actively mode-locked laser. The Tsunami produces 100fs laser pulses with a bandwidth of 10nm locked to the 79.3MHz reference.

Spitfire lasers 1 and 2 are combined in a cross-correlator and the FWHM is calculated. The detector is a Hamamatsu G1117 GaAsP photodiode that is used to measure the TPC of the combined signals. The photodiode response is integrated with a SRS gated integrator and data is collected with an oscilloscope. The oscilloscope waveform is passed to LabVIEW for analysis.

The gross timing between the lasers is matched first through electronics by delaying the 600Hz triggers to laser 2. This brings the lasers to within the 6.3ns allowed by the time quantization imposed by the 79.3MHz reference. Second, a gross delay stage is adjusted to bring the relative timing to within 1ns. Finally, the micrometer stage is centered on the cross-correlation peak. Each laser is auto-correlated and its FWHM calculated. The cross-correlator is converted into an auto-correlator with the addition of the optional beamsplitter. See Figure 1 for a diagram of the experimental setup. The correlations are conducted by moving the delay stage at a fixed velocity while recording the photodiode response at fixed time intervals. The auto-correlation traces contain approximately 6,000 laser pulses. The cross-correlation traces contain approximately 600 laser pulses.

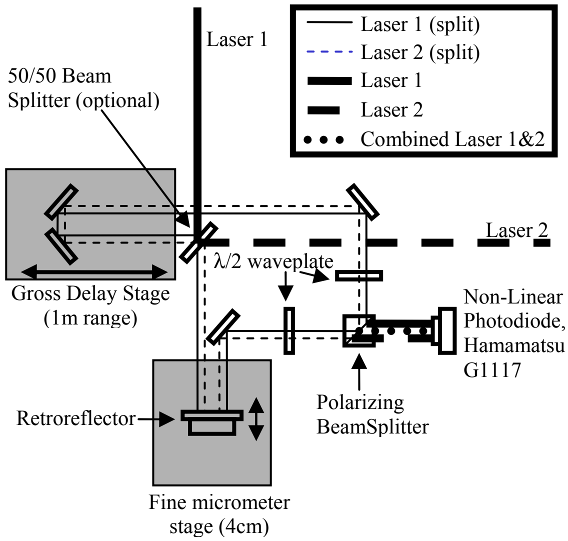

Fig. 1. Experimental Setup. Note the optional beamsplitter that is inserted to convert between cross- and auto- correlation.

RESULTS

Figure 2 shows the results for the cross-correlation measurements. On the left is the plot of a representative data set. The data points in blue at the bottom of the plot were rejected due to laser mistriggering. Mistriggering is defined as the laser pulse failing to temporally coincide with the 60Hz reference. The FWHM was determined with a Gaussian least squares fit. The error was determined by bootstrapping the data with a 10% sample

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100 times and calculating the standard deviation. Results for 25 data sets are shown on the right. The average is 0.758+/-0.018ps FWHM.

Figures 3 and 4 show the results from the auto-correlation of lasers 2 and 1 respectively. The plots on the left show a representative data set. Points in blue were rejected due to laser mistriggering. The graphs on the right show results from all data taken. The averaged FWHM for laser 2 is 0.721+/-0.010ps. The averaged FWHM for laser 1 is 1.085+/-0.091ps. Statistics were calculated as above.

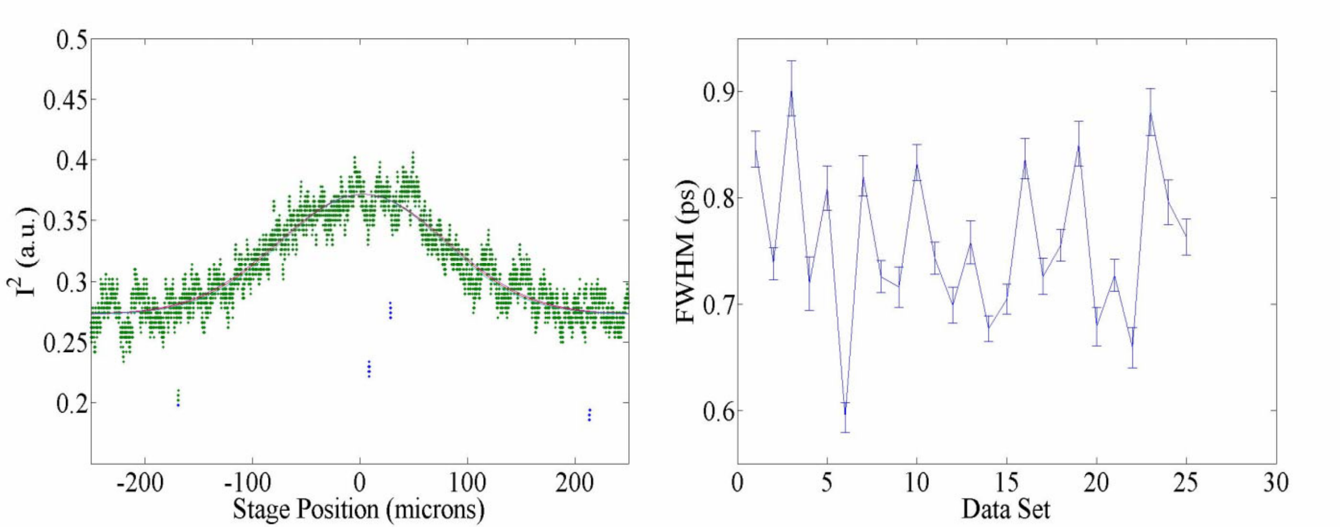

Fig 2. Cross-correlation of Lasers 1&2. The right is a typical data set. The left is the results for 25 data sets. The average is 0.758+/-0.018ps FWHM.

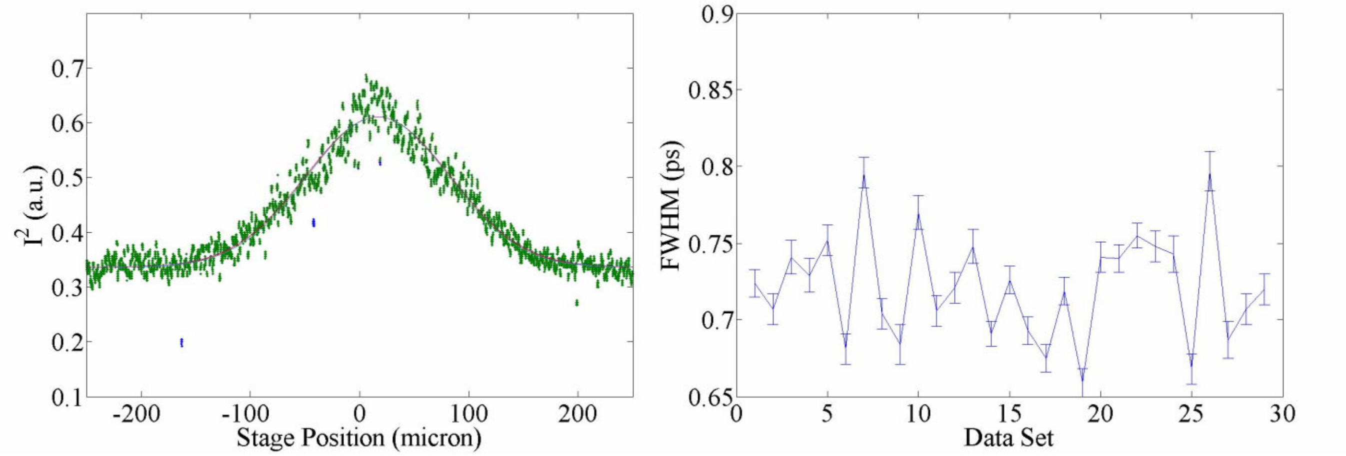

Fig 3. Auto-correlation of Laser 2. The left is a typical data set. The right is the results for 29 data sets. The average is 0.721+/-0.010ps FWHM.

DISCUSSION

The contrast ratio between the correlation peak and the background is near the optimal value of 2:1 for laser 2. The contrast ratio for laser 1 and consequently the cross-correlation is closer to 1.3:1. This is attributed to greater shot-to-shot amplitude instabilities in laser 1. Possible causes of laser 1's amplitude instabilities include timing jitter between the Evolution pump laser and the 79.3MHz reference, and temperature variation within the Ti:Sapphire rod. The standard deviation of the Evolution timing jitter is approximately 60ns. In comparison, the timing jitter of the Merlin is 10ns. Laser 1 has an output power of 1 W. Laser 2's output is 180mW. The cooling system for both rods is known to be barely adequate. Consequently, each gain medium experiences a different thermal environment causing shot-to-shot variations due to non-constant thermal lensing.

The Spitfires experience different types of variations depending on the time scale in question. Both exhibit typical Gaussian shot-to-shot variations. Additionally, laser 1 exhibits a non-Gaussian distributed amplitude variation that occurs on the order of seconds. This variation occurs as sharp peaks and troughs in a plot of intensity vs. time. Finally, the amplitude of both lasers drifts by as much as 20% on the scale of minutes. The latter two classifications are also attributed to thermal fluctuation.

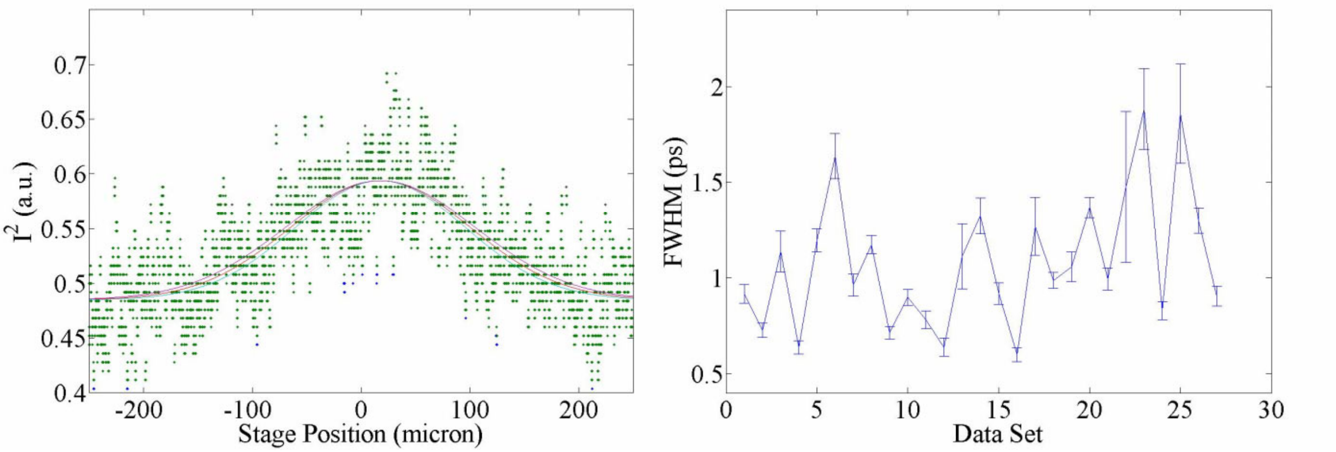

Fig 4. Auto-correlation of Laser 1. The left is a typical data set. The right is the results for 27 data sets. The average is 1.085+/-0.091ps FWHM.

The effects of amplitude drift can be seen in figures 2-4. Sixty-eight percent of the data points do not lie within the mean +/- the standard deviation as would be the expected for a purely Gaussian system. Each data set was taken over a period of 10 seconds with 30 seconds between iterations. The 10 second interval was specifically chosen to balance the need to gather data for accurate statistics and to minimize the effects of amplitude drift on each data set.

Though lasers are generally operated at saturation, it was determined that operating the Spitfire lasers at saturation causes a pulse width variation that is amplitude dependant. To remove this source of error, the lasers were operated at a point near, but not at saturation. This was accomplished by maximizing the power output by adjusting the number of times the seed passed through the gain medium. Then the number of amplification passes was reduced by one. Figure 5 is a plot of the response from a G1117 photodiode versus the response of a linear photodiode. Note the desired linear relationship between non-linear photodiode response and the square of the linear photodiode response.

The upper bound for the relative timing jitter between Spitfire lasers 1 and 2 is less than 0.758ps. The initial intent of the experiment was to measure the relative timing jitter between the lasers by summing in quadrature the FWHM pulse widths of each laser and subtracting this value from the FWHM width of their cross-correlation. Since the mean pulse width of laser 1 is actually larger than the cross-correlation, the best that can be inferred is that the relative timing jitter between the lasers must be less than their cross-correlation.

An effective means of minimizing the Spitfire's pulse length is to adjust the position of the retroreflector in the compression stage of the Spitfire laser such that the response from the G1117 photodiode is maximized. This technique offers advantages over other correlation techniques in that it is fast, simple, and relatively inexpensive.

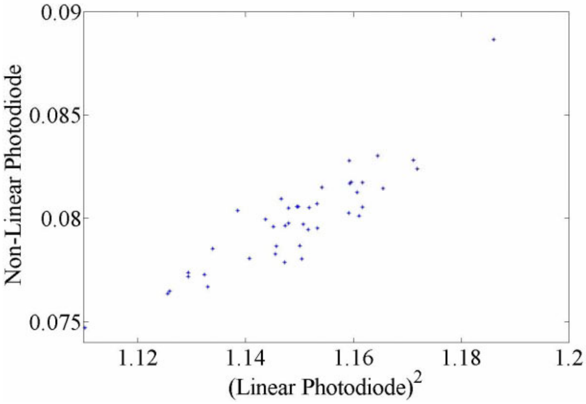

Fig 5. Non-linear photodiode vs. linear photodiode of laser 2. The response from the G1117 photodiode is plotted versus the square of a linear photodiode response.

CONCLUSION

The relative timing jitter between two Spitfire, 800nm lasers is sufficiently small to conduct the E-163 laser acceleration experiments. The cross-correlation method developed for this measurement has many advantages over other more conventional means such as a scanning auto-correlator. The method explored in this paper is straightforward and relatively inexpensive and can be employed for systems with low repetition rates. Efforts are underway to improve this measurement by enhancing the laser cooling system.

REFERENCES

[1] Yoshihiro Takagi et al, "Multiple- and Single-shot autocorrelator based on two-photon conductivity in semiconductors." Optics Letters, Vol. 17, No. 9, May 1, 1992.