Co-Timing UV and IR Laser Pulses on the OMEGA EP Laser System

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Independently managing the timing of individual beams so they all arrive at the target at the time specified by the principal investigator is crucial to the success of experiments on the OMEGA EP Laser System. A streak camera is used to observe the x rays emitted when the laser beams strike a gold target, while an optical streak camera is used to measure the UV pulses. Correlating the signal on the two instruments gives a timing accuracy of 10 ps for the short-pulse IR beams and 20 ps for the long-pulse UV beams.

OMEGA EP is a four-beam, kilojoule-class laser system.[1] The four beams can be configured to produce different pulse shapes with durations ranging from 100 ps to 10 ns and energies up to 10 kJ with a wavelength of 351 nm, or up to two of the beams may propagate to the target chamber without being converted to the UV. Instead, the IR light passes through a grating compressor[2] and is delivered to the target as a 1- to 10-ps Gaussian pulse with up to 1 kJ of optical energy. The users of this facility can perform experiments where the beams arrive at the target with adjustable relative delays.

If two pulse shapes are identical, an overlap can be used for alignment as in shown in Fig. 1(a). For non-identical pulse shapes, the timing criteria become more complicated as shown in Figs. 1(b) and 1(c).

OMEGA EP has adopted the following conventions for co-timing the various beam configurations: UV pulses are considered to be co-timed when the points on the rising edge, corresponding to the 2% level of the peak, reach the target simultaneously. For the IR beams, co-timing means that the peak of the Gaussian pulse shape arrives at the target simultaneously, regardless of the width of the pulses. When both IR and UV pulses are co-timed, the peak of the IR Gaussian is aligned with the 2% point on the rising edge of the UV pulse. Of course, any of the beams can be mistimed to produce the arrival times desired by the principal investigator, but the mistimings are always specified relative to the timed definitions.

The co-timing system begins by recording the UV pulse shapes on an optical streak camera[3] as shown in Fig. 2. The signals arrive at the streak camera arbitrarily but at deterministic and reproducible times resulting from the optical-path differences from the pickoff. The arrival times at target chamber center are determined by x rays generated by the optical pulses and measured on an x-ray streak camera. Also recorded on the optical streak camera is an eight-pulse, 1.8-GHz comb pulse tied to the master clock of OMEGA EP. This fiducial links the measured optical pulse to the outputs of the other diagnostics on the system, thereby enabling one to convert the relative timings measured on the streak camera into absolute system times. The PJX x-ray streak camera, developed at LLE,[4] allows one to measure an x-ray pulse with picosecond time resolution and can be mounted in a ten-inch manipulator directly on the OMEGA EP target chamber. Figure 3 shows the output image of the PJX streak camera for the two different timing configurations.

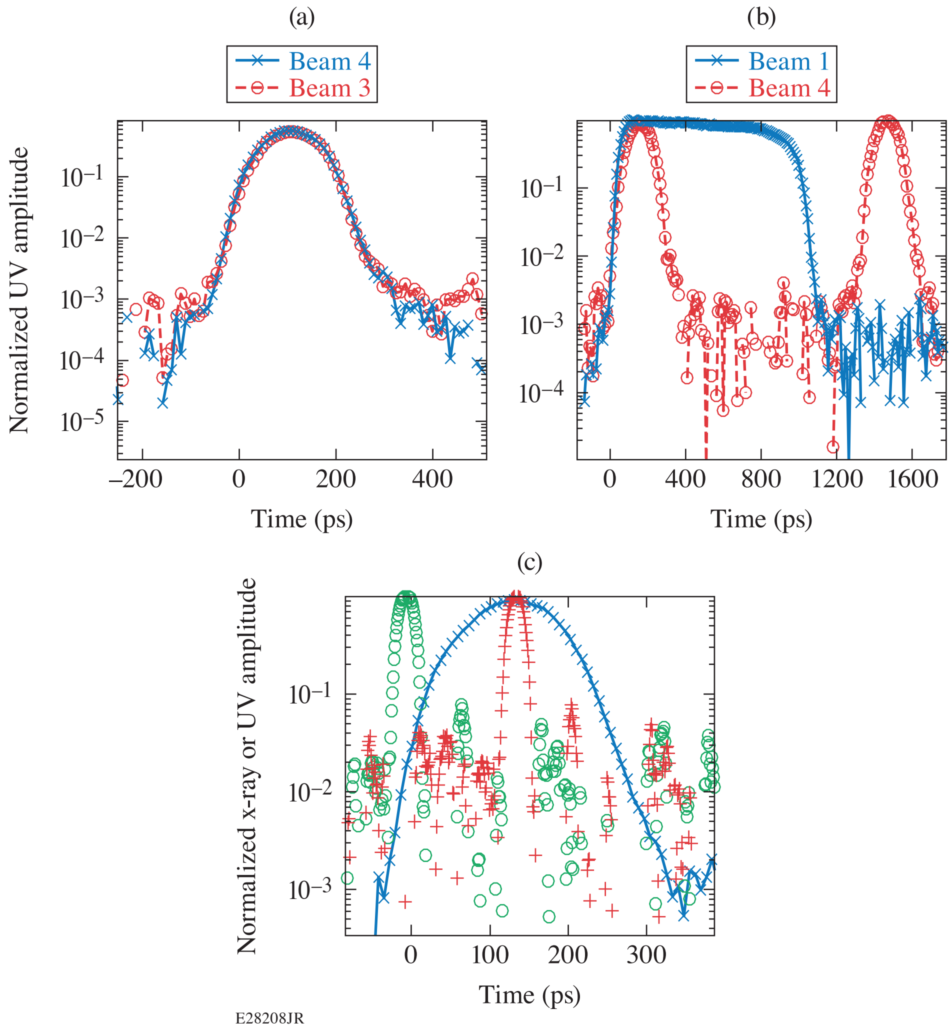

Figure 1
(a) The temporal alignment of two UV pulses with identical shapes. Any point can be used for the alignment. (b) Two dissimilar UV pulse shapes must be aligned by matching equal normalized amplitude points on the rising edge. (c) The UV (blue ×'s) and IR (green circles) are timed such that the peak of the IR pulse coincides with the 2% point of the UV pulse. An alternative timing where the peaks coincide is shown by the red crosses. This timing is not applicable with all UV shapes.

If the system is properly co-timed, the leading x-ray image of each of the four UV beams, shown in Fig. 3(a), should align in the temporal (vertical) direction. In the short-pulse to long-pulse configuration, shown in Fig. 3(b), the peaks of the two short-pulse beams should align with the 2% point on the leading edge of the long-pulse UV beam. Exact timing at the picosecond level requires a quantitative analysis of these images.

The target consists of a 25-μm-thick, 3-mm × 3-mm sheet of polyimide coated with 0.5 μm of gold. The total energy in each UV beam is ~170 J, giving ~85 J in each of the two 100-ps Gaussians; therefore, the peak intensity is ~5×10^{15} W/cm^2. At this intensity, at 351 nm, the temporal profile of the x-ray pulse matches that of the UV pulse as seen in Fig. 4. The x-ray temporal

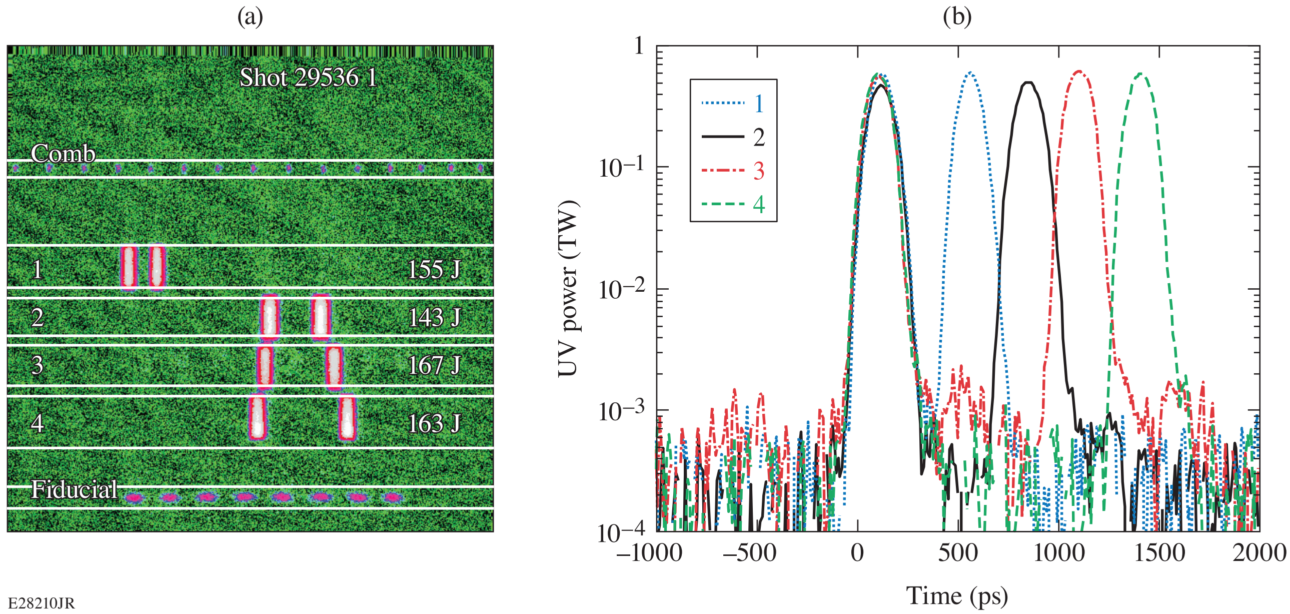

Figure 2
(a) The raw image from the UV streak cameras showing the four double-Gaussian pulse shapes and the two timing comb pulses; (b) the integrated lineouts from the UV ROSS camera of the four beams with the calibrated temporal alignment applied.

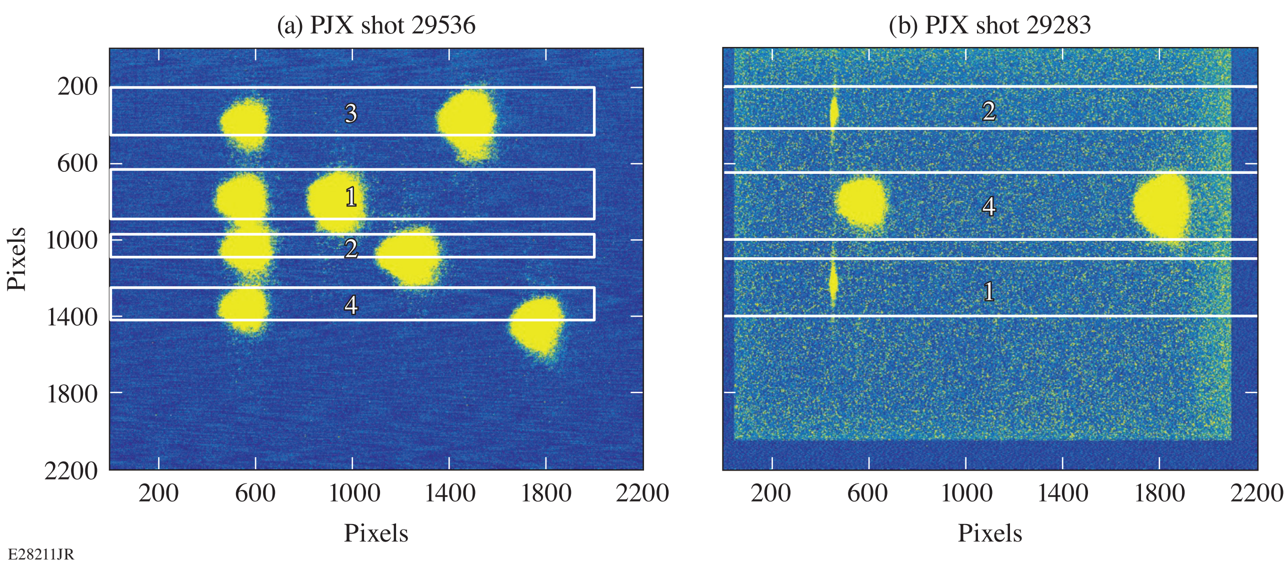

Figure 3
(a) The x-ray streak-camera image of a four-beam, long-pulse shot showing eight pulses from the four beams. (b) Two short-pulse IR beams and one UV beam strike the target. The temporal calibration is ~1 ps per pixel.

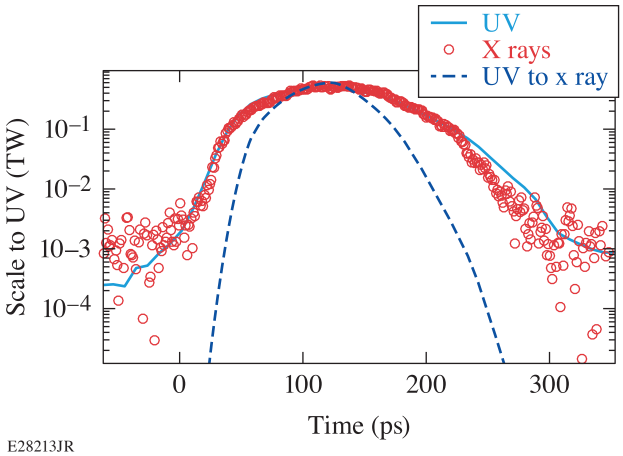

Figure 4
The x-ray temporal pulse shape (red circles) matches the measured UV pulse shape (solid blue line). The dashed blue line is the UV optical power raised to the 3.4 power, which is typical of UV to x-ray conversion at lower powers and obviously does not match the x ray at these intensities.

pulse shape matches the measured UV pulse shape. At intensities below 10^{14} W/cm^2, the emitted x rays typically follow the UV power to the 3.4 power.[5] When the UV optical power is raised to 3.4 power, the power-law conversion obviously does not match the x-ray temporal profile. This is advantageous in processing the data because when the x-ray and UV peaks are aligned, the 2% points on the leading edge, which are the actual timing points, are also aligned.

This is particularly important when timing the short-pulse beams. The IR pulses are treated differently. The shortest pulse duration, 1 ps, is at or below the resolution limit of the PJX streak camera, so the timing campaigns operate with IR pulse durations of 10 ps at best focus of the laser system. No substructure can be discerned in the x rays generated by the IR pulses. The IR x-ray data are fitted with a Gaussian to find the peak. It is worthwhile to note that the 2% point on the IR-generated x ray is at or below the noise floor, making that point inaccessible.

The UV-to-UV and UV-to-IR timing campaigns are run every three months, typically with a three-month separation between the two types of campaigns. The typical variations are less than the 20 ps, which is actually better than the current OMEGA EP timing specification of 25 ps for all beams. Therefore, OMEGA EP maintains a beam-to-beam timing of 20 ps by simultaneously measuring the optical pulse and the x rays generated when that optical pulse strikes a gold target. By operating in a high-intensity regime, the x ray's pulse shape closely tracks the optical pulse, which facilitates the timing.

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