Comparing temporal contrast measurements taken in the Vulcan front-end and target area petawatt

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Abstract

Producing high-intensity laser pulses with a high temporal contrast is essential to establishing the mechanisms that drive particle acceleration at petawatt class laser facilities. We present measurements taken in both the Vulcan front-end and target area petawatt (TAP) using a third-order cross-correlator that demonstrate a contrast of 10^{10}. Comparing these measurements with a historical scan infers that changes to the front-end can have a significant effect for the pre-pulses arriving in TAP.

1 Introduction

Laser pulse contrast measurements with a high dynamic range provide useful information at large-scale laser facilities. Obtaining a high dynamic range, enables direct observation of pre-pulses at much lower intensities to the main pulse. Pre-pulses, pedestals and amplification stimulated emission (ASE) can be undesirable, strongly influencing the behaviour of the plasma. In laser-solid interactions, a pre-pulse can break down the front of the target creating a long plasma density gradient prior to the arrival of the main compressed pulse [1]. For experiments that highly depend on intensity and contrast ratio, a large pre-pulse could explode the target entirely [2]. The contrast ratio plays an important role in many areas of plasma physics, for example, in the pointing angle for laser Wakefield Acceleration (LWFA) schemes [3], relativistic laser-matter experiments [4] and in laser-driven acceleration of ions [5] and protons [6].

Characterisation of the laser temporal envelope may be achieved using an autocorrelator (AC) [7] or a third-order cross correlator (TOCC) [8]. The AC is used to measure the pulse duration while the TOCC provides the temporal contrast. Third-order cross-correlators are ideal for contrast measurements for a few reasons, namely the output signal scales cubically with the input signal meaning that changing the intensity by one order of magnitude will change the output signal for 10^3. An additional advantage is the low noise at the third-harmonic wavelength, which cannot be created in the nonlinear crystals, apart from as a surface effect as it cannot obey any phase matching conditions. Lastly, an autocorrelator will generate a symmetrical pre and post-pulse with the same magnitude whereas it does not in a TOCC device, i.e the TOCC has temporal asymmetry. In this report, building on previous measurements to enhance ASE contrast [9], we will compare measurements of the temporal contrast in the Vulcan front-end and in target area petawatt (TAP). This will provide an understanding on how artifacts in the front-end can manifest in the target area. Understanding how these arise in the compressor or amplifier chain will be crucial information to retrieve for users of the TAP beamline. The primary aim of this investigation is to understand how pre-pulses in the front-end propagate to the target area.

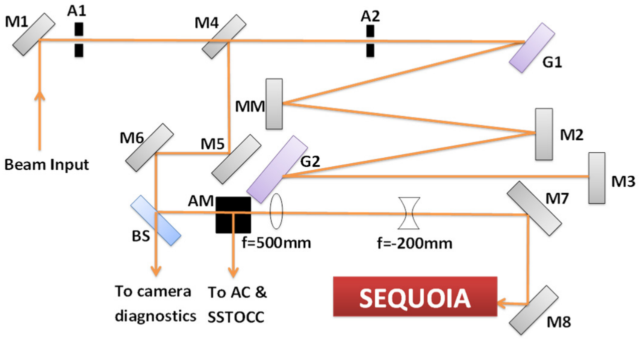

Figure 1: Schematic of the compressor table showing the input beam hitting mirror M1, passing through apertures A1 and A2 onto the compressor gratings (G1 and G2). The beam is then focused into the Sequoia.

1.1 *High Contrast Device*

The laser pulse contrast was measured using the Sequoia TOCC designed by Amplitude Technolgies. It works by generating a non-collinear third harmonic signal through mixing the fundamental with the second harmonic (SH) in a non-linear BBO crystal. The third-order cross-correlation is defined as follows

$$TOCC(\tau) = \int_{-\infty}^{\infty} I^2(t-\tau)I(t)dt \qquad (1)$$

where $I^2(t-\tau)$ is the second harmonic and hence measured at the second harmonic wavelength and $I(t)$ is the

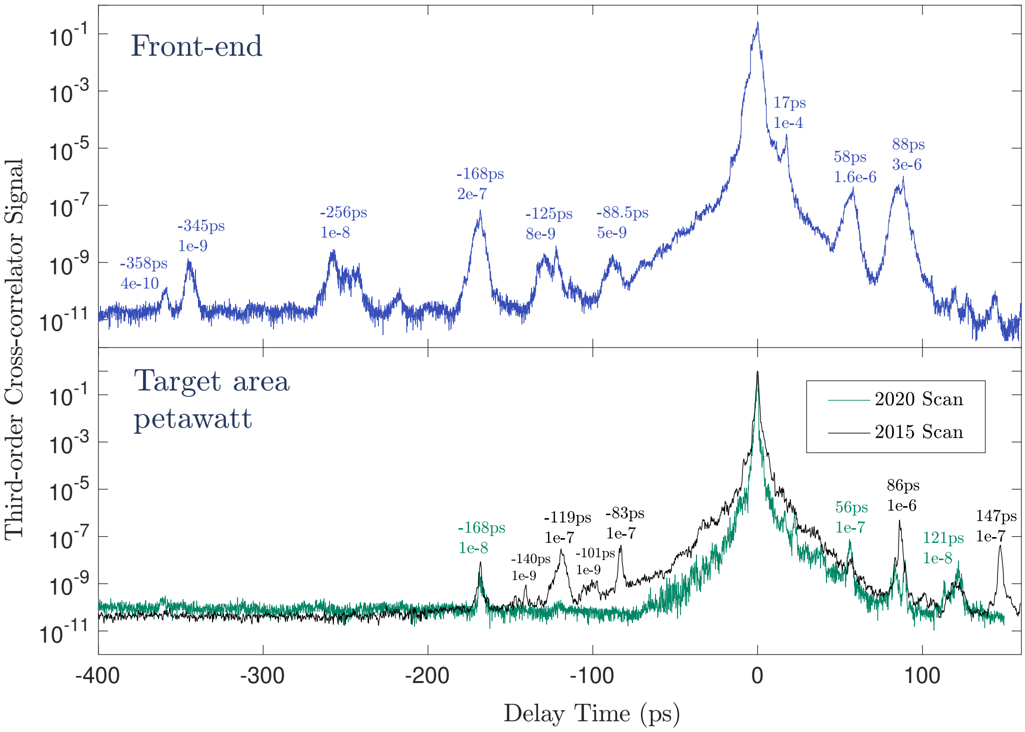

Figure 2: Third-order Cross-correlator measurements from the front-end and target area petawatt along with a historical 2015 scan. A single pre-pulse is left at -168ps at 10^{-8} in the target area after changing optics in the front-end.

intensity at the fundamental wavelength. The TOCC signal (which is the SFG between the previous two) is measured at the third harmonic wavelength. Before the final detection instrument we have a spectrometer-like assembly that can better distinguish the fundamental from the third harmonic then the SH from the third harmonic. In order to minimise noise we also have a small angle between the fundamental and the second harmonic which means that the SFG will be in the middle of both of them. Therefore, the dynamic range is limited by the second harmonic arm of the device.

2 Experimental Setup

Contrast measurements were initially taken in the Vulcan front-end. Vulcan is a petawatt class ultra-intense laser [10] which uses OPCPA to explore high-energy density (HED) physics. Integral to delivering high-intensity pulses is the front-end which consists of a Ti:sapphire seed and a ns OPCPA pump [11] operating at 2Hz repetition rate. There is also a ps OPCPA which is important for improving the ns contrast. The OPCPA is either injected into Vulcan or, onto the test compressor shown in figures 1 and 3.

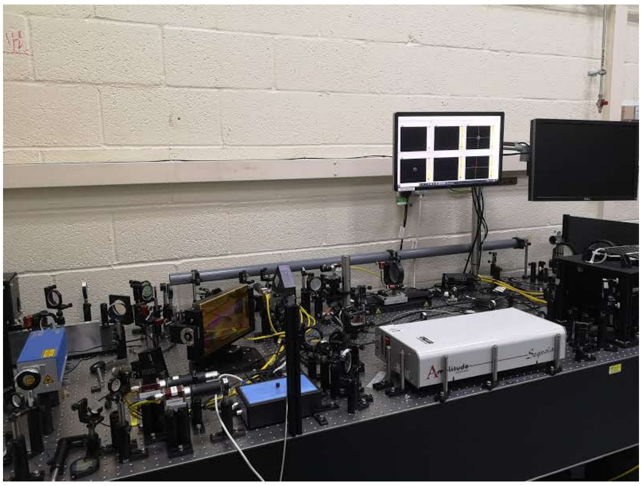

Figure 3: Vulcan Front-end test compressor system.

2.1 *Test compressor*

The investigation commenced in the Vulcan front-end with the test compressor. The test compressor as described in [12] has the gratings G1 and G2 which after the second pass a beam splitter sends the beam into an autocorrelator and the TOCC. Producing a high contrast scan is highly sensitive to both the pulse energy and duration. Therefore, a pulse that is not optimally compressed will not present an optimal TOCC trace. Moreover the ratio between the compressed pulse and other features of the pulse will change since these features will not be as sensitive to the spectral phase of the system as the pulse itself. This was the case in our test compressor. In fact, plotting the TOCC signal on a linear scale demonstrates that the pulse is asymmetric which means it is not fully compressed, figure 4.

Initially, a window of 700ps was measured in order to scan a large temporal window. The average energy entering the TOCC was measured to be approximately 100μJ. This was to ensure that the energy was sufficient for second and third harmonic generation to occur in the Sequoia BBO crystals.

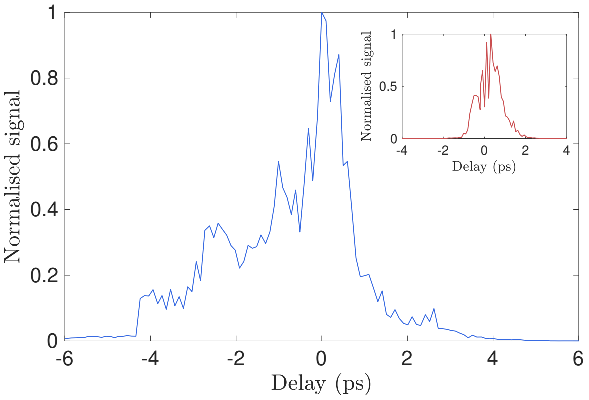

Figure 4: Asymmetry observed in the front-end linear scan suggests that the pulse is not optimally compressed as it is in the target area (inset).

2.2 *Target area petawatt*

The TOCC was set up adjacent to the interaction chamber in TAP, shown in figure 5. A bypass has been used which takes the pulse from the front-end to the target area directly without propagating through the Vulcan chain. This was done to avoid the losses through the main part of the Vulcan amplification chain. The pulse was aligned through the compressor and chamber, onto a periscope and finally to the cross correlator. The energy measured at the aperture was approximately 130μJ, 60μJ inside of the aperture. Outside of the TOCC the energy was 200μJ. This was measured to ensure there was enough energy to produce a strong signal from the second harmonic arm of the device. Diagnostic cameras were also set up to ensure the beam was entering the TOCC correctly.

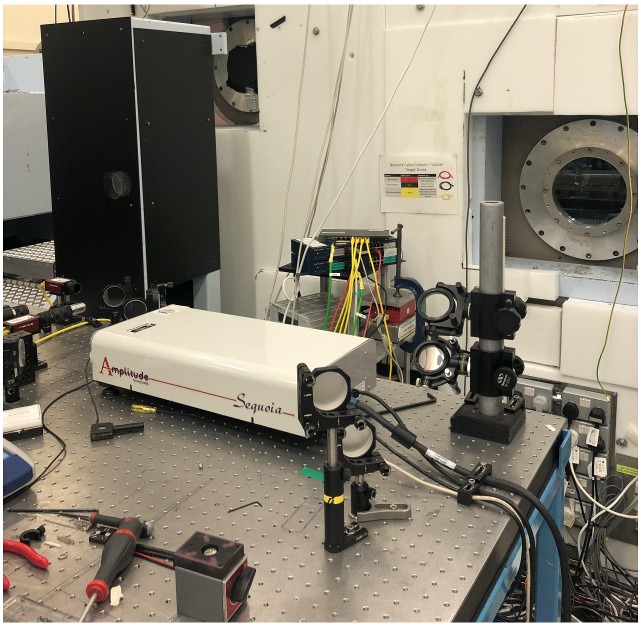

Figure 5: Target area petawatt (TAP) setup of the Sequoia third-order cross-correlator.

3 Contrast Measurements

The contrast scans, measured in the front-end (blue) along with the target area scan (green) and a previous historical scan taken in 2015 (black) can be seen in figure 2. The pre-pulses arising in the front-end on the test compressor can be justified from ghost reflections. The by-pass has spatial filtering and therefore minimises pre-pulses below the background noise meanwhile the test compressor does not.

A single pre-pulse is found in TAP at 168.6ps with contrast 10^{-8} corresponding to an intensity 10^{13}Wcm^{-2}. This remaining pre-pulse is suspected to be due to a double reflection in the BBO OPA crystals. Consider the time difference of the two reflected paths

$$\Delta t = \frac{2Ln}{c}$$

where L is the length of the crystal (15mm in the front-end). Taking $L = 15$mm and $n = 1.67$ gives $\Delta t = 167$ps, a delay similar to the observed TAP pre-pulse. Figure 2 also infers that the pulse in the front-end may not be optimally compressed. The FWHM of the trace recorded in the front-end is 1.67ps while it is 0.98ps in the target area showing there is a difference in compression between the TAP and test compressors. Observing figure 2, there is clearly a higher pre and post-pulse at the times -119ps and 121ps respectively in the 2015 scan. These prepulses are attributed to a postpulse to prepulse conversion, a smaller conversion can be attributed to smaller non-linearities in the laser chain. The background noise in the front-end is $\sim 10^{-11}$, while it is lower in the target area $\sim 10^{-10}$, in other studies this has been a consequence of optical diffusion in surfaces [13]. Another significant change in the front-end has been the replacement of BBO crystals on the first and second stages of the ns OPCPA in 2016. One of the crystals has a 0.5° and 1° wedge in order to reduce reflections inside the crystal.

4 Discussion

Improving pulse contrast can be challenging in practise as pre-pulses can arise from a variety of sources. For example, backward facing mirrors, double reflections within laser cavity optics, spectral clipping, misaligned compression of the pulse while passing through the test compressor gratings and 'cavity bleeding' from regenerative amplifiers [14]. Plasma mirrors (PMs) offer an attractive way to remove such pre-pulses, however at the expense of being costly in high rep rate experiments [15]. Another consideration is performing a future D-scan [16] as this would ensure the pulse is optimally compressed in the front-end. The single pre-pulse left at -168ps in the 2020 scan of figure 2 is several orders of magnitude below the intensity threshold for ionisation $I \sim 10^{14-16}\mathrm{Wcm}^{-2}$. Ginzberg et al reports that achieving a dynamic range of 10^{10-12} is crucial for measuring pre-pulses with intensity $\sim 10^{12}\mathrm{Wcm}^{-2}$ [17]. We are therefore in the contrast regime where pre-pulses in TAP can be measured sufficiently. While the Sequoia contrast scans are of great value for detecting and removing pre-pulses, the scans also take a significant amount of time due to the low 2Hz repetition rate of Vulcan. This also makes it impossible to use a scanning TOCC for shot-to-shot contrast measurements in target area petawatt. It would be advantageous for future work to involve the target area to take on-shot contrast measurements with a single-shot TOCC diagnostic. There are reports of single-Shot TOCCs that have been built with a dynamic range of $> 10^9$ [18]. Crucially this future work for an operational single-shot design would have to be modified to achieve a high-dynamic range which is $> 10^9$.

5 Conclusion

In conclusion, a contrast scan of dynamic range 10^{10} has been achieved using a third-order cross-correlator. We have demonstrated that while pre-pulses arriving in the target area can arise from unknown sources, modifying parts of the front-end can significantly reduce target area pre-pulses. We have compared the contrast in both the front-end and target area with historical data providing updated contrast measurements for the facility. Understanding how pre-pulses in the Vulcan front-end arise in the target area will give beamline users access to high-contrast laser pulses required in experimental campaigns.

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