A report on the commissioning of the Gemini experimental target area

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Introduction

The new Gemini laser system is an upgrade to the existing Astra laser in the CLF, providing a dual beam facility with 0.5 PW power on each beam. Simultaneous access to the dual beams makes it a unique facility for studying ultrafast phenomena at ultrahigh intensities. Gemini will operate in a configured access mode (a fixed F/20 and F/2 focusing geometry) for the first few years in order to minimise set-up time for each experiment.

Commissioning work has been carried out in the new Gemini target area (see figure 1) to test the performance of the laser and various target area systems. This included the troubleshooting of the interlock, control and vacuum systems as well as the beam delivery optics and mounts. The commissioning was completed in two phases: the first phase involved a basic layout with F/2 focusing geometry and delivered the first Gemini shot onto a solid target in September 2007. The interlock commissioning and a basic radiological commissioning were also completed. The layout was then switched to a F/20 geometry.

Figure 1. Inside the Gemini target area, showing the parabola chamber and target chamber.

The second phase was done in conjunction with the first user experiment in Gemini and it involved characterisation of focal spot, pointing stability, vibration, etc. in the F/20 geometry. The following sections provide details about the commissioning.

Characterisation of laser parameters

The pulse duration was measured in the target area, using a small portion of the beam. A single shot Grenouille (Swamp optics, 8-20 USB) was used for this. The grenouille trace is shown in figure 2, indicating a 45 fs pulse, with a symmetric spectral profile.

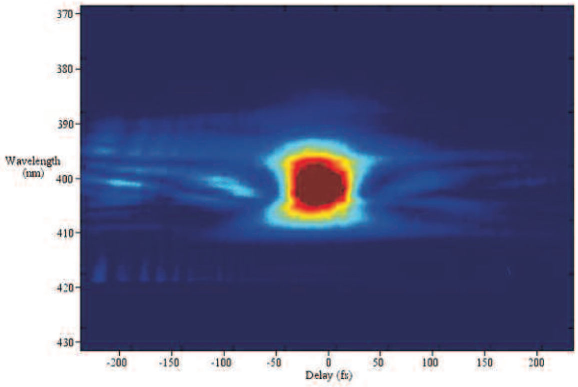

Figure 2. Frog trace showing 45 fs pulse in the target area.

The pulse contrast and presence of any prepulses in nanosecond time-scales are very important in the intensity regimes that Gemini operates in. The presence of a preplasma will alter the physics of the main pulse interaction. A third order autocorrelation (Sequoia) indicated that the pulse contrast in picosecond timescales is better than 10^{-7}. It is, therefore, unlikely that a strong preplasma would be present in the intensity ranges available in F/20 geometry used in the first round of experiments. The prepulse contrast in nanosecond levels was measured using a fast photodiode in the laser bay. Careful alignment and a saturable absorber in the laser chain ensured that the prepulse/ASE levels in nanoseconds are insignificant, as indicated by the photodiode trace in figure 3.

Beam delivery commissioning

The target area can avail different modes of the Gemini laser system, depending on the purpose. Table 1 summarizes the different laser modes.

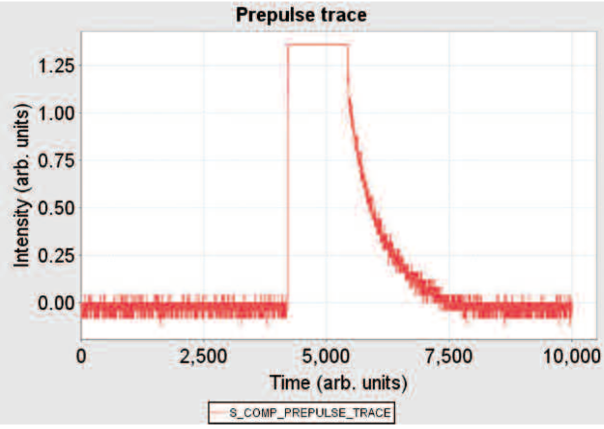

Figure 2. Frog trace showing 45 fs pulse in the target area.

	Pulse Energy (J)	Pulse Peak Power	Max Repetition Rate (Hz)
Full Power	15	500.00 TW	0.05
High Power	0.6	20.00 TW	1
Medium Power	0.006	0.20 TW	10
Low Power	0.0003	10.00 GW	10

Table 1. This table shows the energy and peak power of the four Astra Gemini laser modes along with their maximum repetition rates. An 800 nm CW laser is also available for alignment.

All the laser modes provide beams which are collinear and 150 mm in diameter. CW and low power modes are generally used for alignment and triggering purposes. Medium power mode is used if the low power is not sufficient for alignment due to losses or for optical harmonic generation. The high power and full power modes are not accessible from within the target area; the area must be evacuated and searched before these modes can be accessed from the control room.

Figure 4 shows the beam layout using a single beamline in F/20 focusing geometry used for the first set of electron acceleration experiments. The first two mirrors and the parabola rotation were used to adjust the line of focus and aberrations.

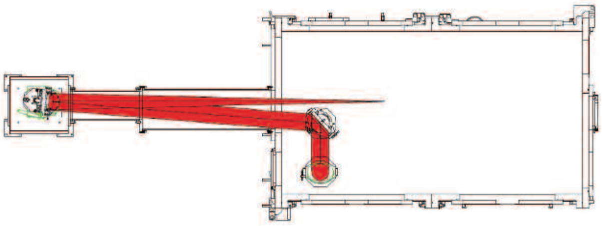

Figure 4. Schematic layout of the beam delivery optics for the first configured access run on Astra Gemini.

The focal spot was imaged in the low-power mode using a CCD camera and a microscope objective kept in the beam path. The beam intensity was controlled with tissue papers inserted in the beam, avoiding saturation. Figure 5 shows the low power focal spot. The focal spot diameter is ~25 microns, close to diffraction limit. The speckle-like structures outside the main spot are caused by aberrations present in the beam either inherently or due to multiple scattering in the attenuating tissues.

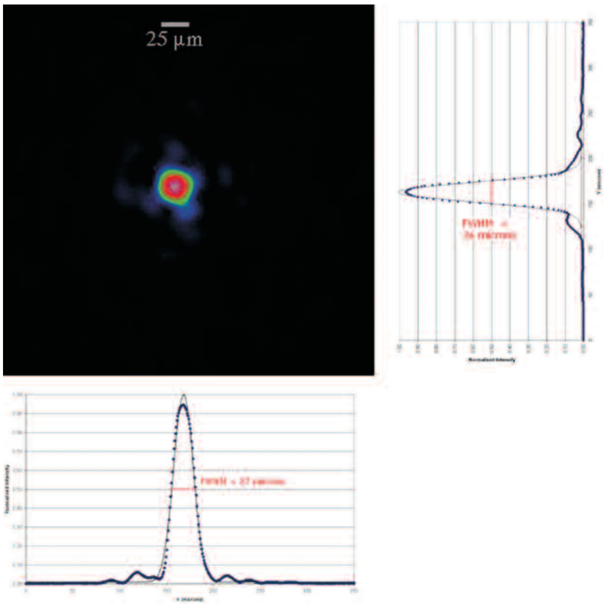

Figure 5. Image of the low power focal spot showing the intensity line outs across the centre with a Gaussian fit.

It is obvious that the focal spot cannot be measured in this method in full power mode; the attenuation required would be enormous. Therefore, a few collection optics – wedges, spherical mirrors etc. – are placed in the chamber to collect the diverging light after focus, re-collimate and image the focal spot outside the chamber. Since these optics would form permanent parts of the set-up for the electron acceleration experiments, the first optic, a wedge, is designed to have a hole in the middle to let the electron beam pass through.

However, at full power, the intensity of the beam can be greater than the damage threshold of the optics, even at defocused diameters. Therefore, the intensity distribution in the beam away from the focus has to be calculated to determine the position of the first optic.

Figure 6 shows the calculated intensity as a function of distance from focus. The horizontal lines indicate observed damage thresholds at two wavelengths, from available literature. The damage threshold of 800 nm would lie in between these two and, therefore, it is clear from the graph that the first optic should not be placed <130 cm from the focus. In our experimental set-up it was placed 150 cm from focus and the collection optics are placed in the chamber accordingly.

Figure 7 shows the full power focal spot imaged using the collection optics. The focal spot was imaged using two

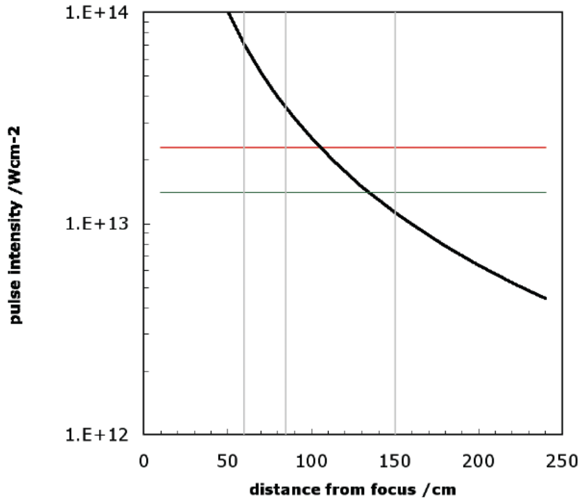

Figure 6. Intensity of the Astra Gemini pulse as a function of distance from focus. Laser parameters: E_L = 15 J, t = 30 fs, *f*/20 divergence. The red and green curves are the approximate damage thresholds for 1053 and 526 nm pulse. The grey lines mark the distances 60, 85 and 150 cm.

spherical mirrors (f=2 m) in a 1:1 geometry. The focal spot diameter was found to be ~30-35 µm FWHM. The spot appeared slightly elliptical in shape; it is yet to be determined if this is due to the aberrations in the beam or those in the collection optics.

Another important aspect for any high-power laser experiments is the shot-to-shot pointing fluctuation. Though low-repetition rate systems are more susceptible to this due to thermal effects, even a relatively higher repetition rate systems like Gemini are not completely free from it. Air currents in the laser beam path, vibrations etc. can cause pointing fluctuations. Figure 8 shows the shot-to-shot fluctuations in the full power beam focus position, plotted in units of spot diameter. In the initial stage of commissioning, this was quite large as the stability of the extension chamber was the biggest source of shot to shot pointing variations. This was minimized in order to give an average pointing error of 0.6 spot widths as illustrated in the figure.

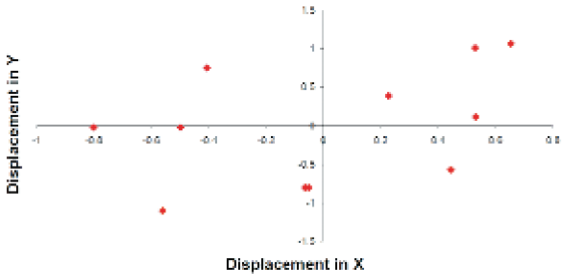

Figure 8. Graph of the pointing fluctuation of the full power focal spot. This shows an average displacement from the centre of 0.6 spot widths.

Figure 7. Full power focal spot imaged using the collection optics.

Radiological commissioning

Before the area was declared open for user access, detailed radiological commissioning was carried out to investigate the dosage and any possibility of activation etc. Over 100 shots were taken onto an aluminium slab using a F/20 geometry and the ionising radiation yields were monitored at various points inside and around the target area. The area shielding was found to perform as expected and continuous radiation monitoring is ongoing throughout active experiments. Before conducting experiments with F/2 geometry, further radiological commissioning will be carried out at the highest intensity.

Laser status

A separate annual report concentrates on the progress made with the Gemini laser. For the present series of experiments, only a single beam will be used, with an option of switching between F/20 and F/2 focusing geometries. The dual beam in Gemini is expected to be ready in March. The current parameters of the system are shown in Table 2.

	Gemini specification	Current status
Energy	15J × Two Beams	12J – South beam only
Pulse length	30fs	50fs
Total power	1 PW	240 TW
ASE contrast	1010	108
Repetition rate	20 seconds per shot	20 seconds per shot

Table 2. The current specification of Astra Gemini and the target specifications.