THE 10 PETAWATT UPGRADE PROPOSAL FOR THE VULCAN HIGH-POWER LASER

D. Pepler, A. Boyle, J. Collier, M. Galimberti, C. Hernandez-Gomez, P. Holligan, A. Kidd, A. Lyachev, I. Musgrave, W. Shaikh, Y. Tang, T. Winstone,
Science & Technology Facilities Council, Central Laser Facility, Rutherford Appleton Laboratory, Harwell Science and Innovation Campus, Didcot, OX11 0QX, UK

Abstract

The Vulcan Nd:Glass Laser Facility [1] at the Rutherford Appleton Laboratory, UK has had a long history of providing high profile science with an International reputation in the field of plasma physics, predominately for a university based user community. Current capabilities of Vulcan include multiple infrared (1.053 micron) beamlines operating in the few hundred picoseconds to several nanoseconds regime with a total energy of up to 1.8kJ, synchronised with a single Petawatt class (10^{15}W, 500J, 500fs) beamline capable of being focussed to an intensity of 10^{21}W/cm^2. It is proposed to significantly enhance Vulcan with the provision of an additional 10 Petawatt (300J in 30fs) beamline capable of generating intensities of 10^{23}W/cm^2 synchronous with the existing single PW system. This paper will provide an overview of and the challenges for the designs of the six year £25M upgrade project [2], in terms of the laser, the high speed timing and synchronisation requirements as well as the computer control systems.

INTRODUCTION

The size of the current Vulcan laser is shown within the dotted frame on Figure 1 at right indicating that Vulcan already has a footprint on the order of two Olympic-sized swimming pools. As can be readily appreciated, the scale of the upgrade proposal is also very significant and essentially amounts to building another Vulcan around and over the top of the original.

The expectation is that the new laser system would be based heavily on the same Nd:glass technology as the present system and so would have a seed oscillator, a series of phosphate glass rod amplifiers, and phosphate glass disc amplifiers which would ultimately deliver two 1.2kJ 3ns pulses. Crucially however, these long pulses would not be sent directly to a target area but are to be frequency doubled to 527nm (resulting in two 600J beams at $2\omega_0$) which form the pump beams for a high energy Optical Parametric Chirped Pulse Amplification (OPCPA) process.

The OPCPA process has been chosen as providing a means of delivering high energy and intensity pulses with high contrast. With flashlamp pumped laser systems amplified spontaneous emission (ASE) potentially generates a continuous background over a 100 µs timescale and which is only reduced by actively gating. With OPCPA the pump for the amplification is another laser pulse of only 3 ns duration, matched precisely to the length of the chirped seed pulse. Phase 1 of this project has been to construct a proof-of-principle front-end oscillator with two stages of OPCPA, the first in the picosecond regime and the second in the nanosecond regime.

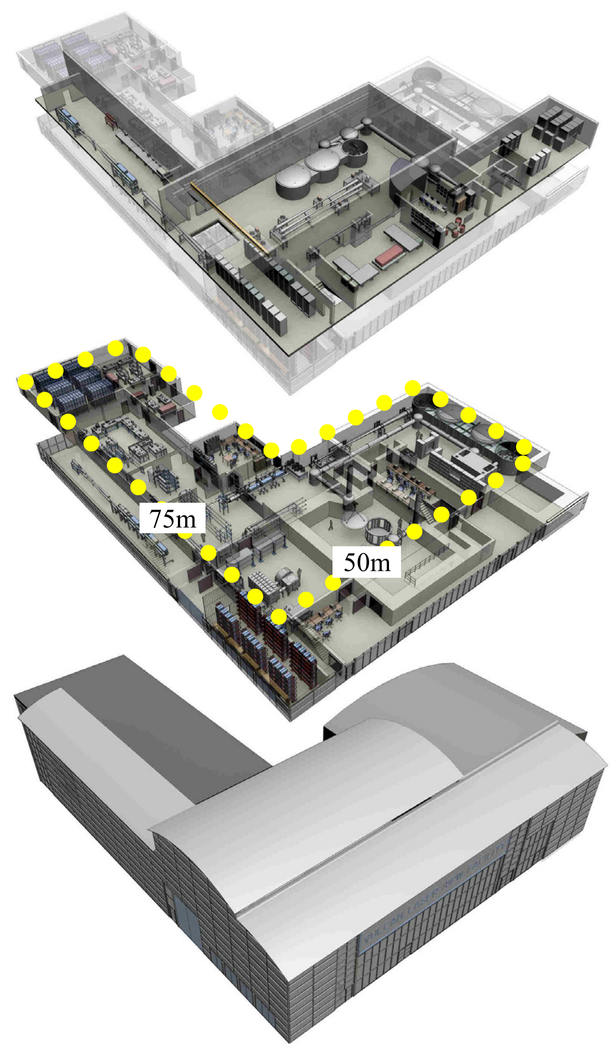

Figure 1: Bottom - Artists impression of the exterior of the 10 PW Facility building. Middle - the ground floor layout. Top - the upper floor layout.

Phase 1 in and off itself has been a highly technical challenge and has been developed over the last two or three years by a dedicated team. This has successfully

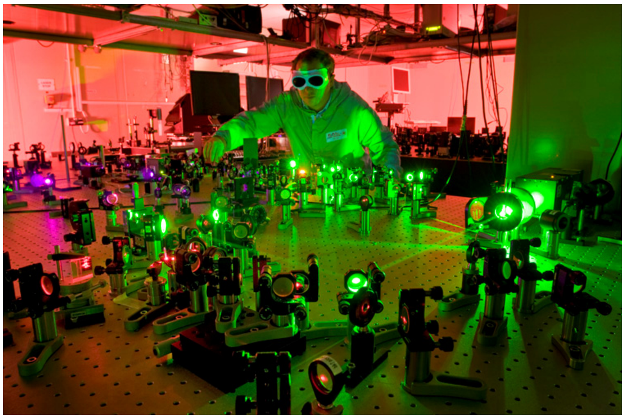

Figure 2: Photograph of the laboratory housing the prototype front-end oscillator and the initial OPCPA amplifier stages for the 10 PW proposal.

demonstrated around 250 mJ in a 3 ns long chirped pulse which is not far off from what is believed to be required for seeding into a third and final high energy stage of OPCPA. Figure 2 is a photograph of the prototype front-end oscillator laboratory showing some of the second harmonic generation (SHG) beamlines.

Generating the 2 x 600J $2\omega_0$ beams and moving the prototype front-end into an operational facility is the subject of Phase 2 which will ensure the provision of a 10PW beamline on Vulcan. Figure 3 shows a basic schematic of the overall design.

OPERATIONAL & CONTROL REQUIREMENTS

The new laser system will be designed to serve its own target area (designated the High Intensity Area) and to have its own dedicated control system. This will allow the existing and the new laser system to each be operated independently during a commissioning phase of the new system.

Once fully commissioned, the philosophy of operations is such that the 10PW system is expected to be remotely controlled from the existing Vulcan control room. The reason for this is primarily one of safety — minimising miscommunications between distant and potentially competing control areas. The general operational policy will be that once the initial daily alignment checks have been completed, the 10PW laser area will be locked-off. System alignment would be constantly monitored (remotely, from the Main Control Room) and minor changes made through the use of automatic controls.

It is planned that whether a 10PW shot is fired into the High Intensity Area (HIA), or a 1PW shot is fired into the Petawatt target area (TAP), each of these would be fired from the Main Control Room with the two computer control systems independently available.

A prime requirement though, will be that the 10PW beamline should also be available to TAP (a so-called "TAP10" configuration). This requirement directly links the two laser systems and requires that the two control systems be locked together (with the existing Vulcan control system as Master, 10PW control as Slave). In the configuration where an auxiliary long pulse (200J, 1ns) or 1PW (500J, 500fs) beam is fired (from the exiting Vulcan laser) along with the new 10PW beam, both laser systems would also be required to run together in a highly-synchronised mode.

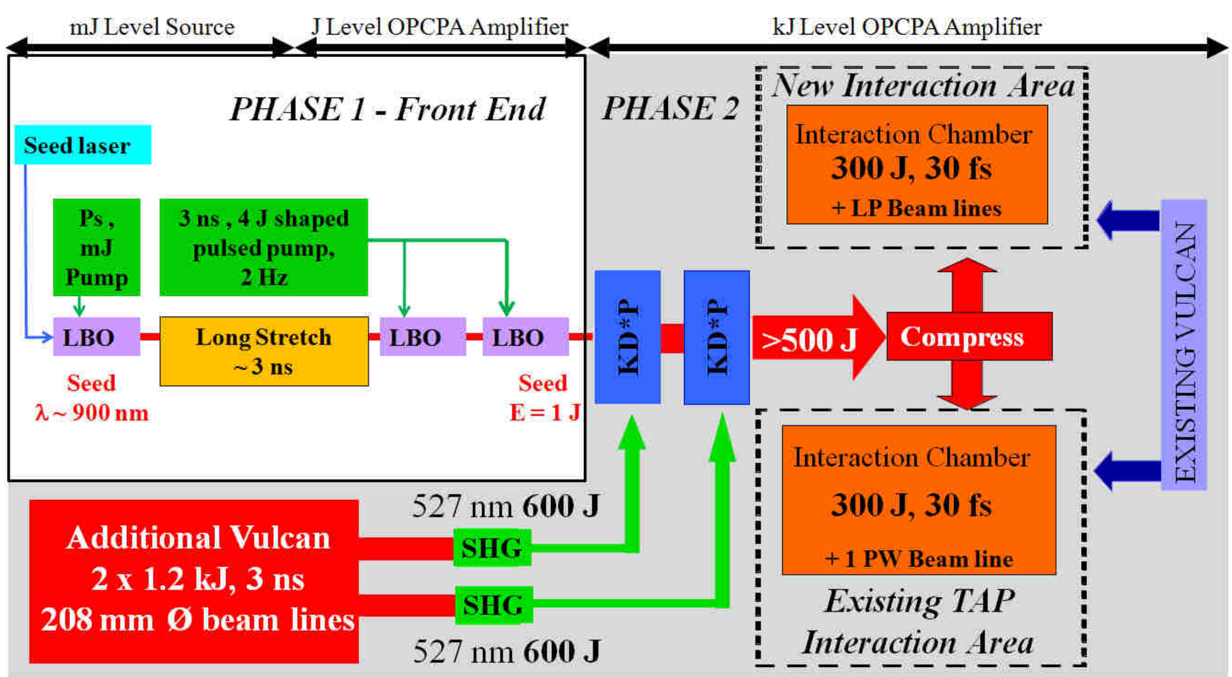

Figure 3: Schematic of the new OPCPA front end oscillator built as an initial proof-of-principle and how it will be integrated into the full system to be built in Phase 2.

TIMING & SYNCHRONISATION

The two laser systems will have similar oscillator, rod and disc amplifiers and these will have comparable capacitor bank power supplies. The rod amplifiers will have charge times of between 5 and 20 seconds whereas the disc amplifiers will take around 40 seconds. Locking the two control systems together will enable this rather slow timescale timing to be relatively easily enabled and achieve a common end-of-charge (EOC). Once the EOC has been reached, hardware electronics will generate more micro-timing signals allowing a range of pre-trigger signals to be cascaded through the system, ranging from 3 seconds early to "prompt" and 500ms post shot. The fast sub-nanosecond triggers at the time of shot will rely on high-speed electronics that will be synchronised to the RF signal generated from the optical output of the prime seed oscillator. More sophisticated and specialised phased locking will need to be applied to the 10PW seed oscillator so that it is precisely in synch with the Vulcan seed pulse.

The methodology for this has yet to be defined but one potential way to achieve this synchronisation is to fibre-optically couple the oscillators. This should provide sufficient feedback to lock them together at source but a major challenge will be to maintain that synchronicity through each of the two laser systems 250m of optics, amplifiers and beam paths. A 30 fs pulse is only on the order of 10 microns long so a very high level of stability and consistency from the lasers will be vital to its success.

CONCLUSION

The 10PW proposal is a highly technical and challenging project but one that will enable researchers to look into new and extreme areas of fundamental physics such as pulsar magnetospheres, proton acceleration and spontaneous pair production in a vacuum.

REFERENCES

[1] http://www.clf.rl.ac.uk/Facilities/vulcan/index.htm
[2] http://www.clf.rl.ac.uk/Facilities/vulcan/projects/10pw/10pw_index.htm.