Overview of Project Orion

C.N. Danson, T.H. Bett, N. Cann, S.J. Duffield, R. Edwards, D.A. Egan, S.P. Elsmere, M.T. Girling, T. Goldsack, E.J. Harvey, D.I. Hillier, D.J. Hoarty, N.W. Hopps, S.F. James, M.J. Norman, K. Oades, S.J.F. Parker, P.D. Roberts, P.A. Treadwell and D.N. Winter

AWE, Aldermaston, United Kingdom

Introduction

Project Orion will provide a facility for performing high energy density plasma physics experiments at AWE. The laser consists of ten long pulse (nanosecond) beam lines delivering a total of 5kJ@351nm with 0.1-5ns temporally shaped pulses and two short pulse Petawatt beam lines, each producing 500J in 0.5ps with intensities to target > 10^21 W/cm^2. An extensive suite of target diagnostics is to be made available. As well as permanently installed diagnostics, Orion has the capability to use removable diagnostics to facilitate better interoperability with other laser facilities and more rapid shot turn around.

Facility Description

A schematic of the Orion facility is shown in Figure 1. The seed pulse for the long pulse is derived from a fibre optic based system housed beneath the laser hall. The initial amplification is in a regenerative amplifier followed by a multi-passed rod pre-amplifier module (PAM). This system spatially shapes the beam and provides optional beam smoothing by spatial dispersion in two dimensions. Its output pulses, at the 100mJ level, are injected in to the final disk amplifier stage. This consists of two stacks of five beam lines, supported on each side of a large space frame structure which are four-passed using angular multiplexing. The output beam is then frequency tripled in the target hall before being delivered to target in two opposing cones of five beams. Focusing is via f/4 lenses with options of focal profiling using phase plates.

The short pulse beams are seeded with pre-amplified pulses from a single commercial mode-locked Ti:sapphire laser, operating with about 12nm of bandwidth (FWHM) at around 1054nm. This is split into two beams and directed into two Offner triplet stretcher systems. The 6ns output from these is directed into pre-amplifier stages based on the Optical Parametric Chirped Pulse Amplifier (OPCPA) principle delivering 50mJ pulses which are image-relayed up into the laser hall. The first stage in each short pulse laser chain is a four-passed mixed glass rod amplifier system to maintain the pulse bandwidth. The short pulse beam line design uses single-passed disk amplifier architecture up to 200mm in diameter. The beams are then expanded to 600mm diameter before being injected into each compressor vessel. The compressed pulses are then transported under vacuum into the target chamber for focusing with f/3 off-axis parabolic mirrors. A deformable mirror, at the 100mm aperture region of the beam line, is used to correct aberrations in the beam to access the highest possible intensity.

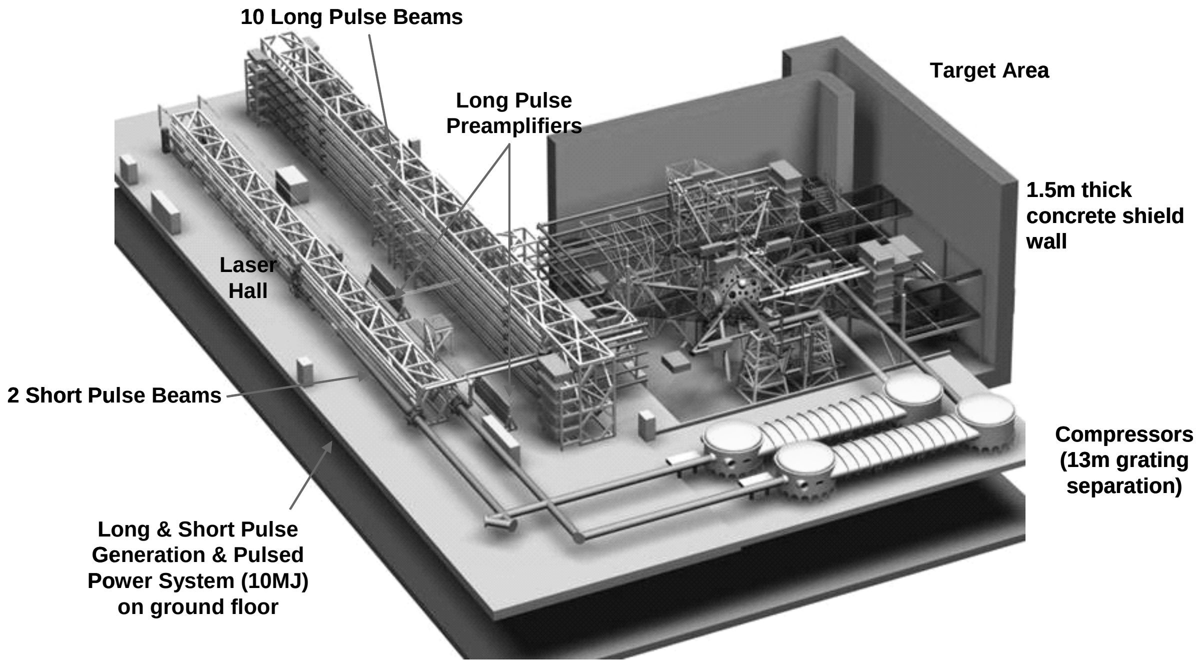

Figure 1: Schematic of the Orion facility

Plasma Physics Programme

The experimental strategy for Orion in the early years of operation is to acquire data to benchmark and underwrite the material modelling capability at AWE. The case for Orion was made on the basis that a combination of long pulse and short pulse laser interactions allow states of matter at extremes of temperature and density to be accessed. Experiments on HELEN (Orion's predecessor) have shown that useful opacity data can be obtained from extremely hot, dense plasma heated by short pulse lasers. On Orion, plasmas will be created at higher density than those on HELEN allowing high temperature opacity experiments to be carried out at conditions closer to local thermodynamic equilibrium.

The combination of long pulse compression and short pulse heating will be used to study a number of dense plasma effects which influence high temperature equation of state and opacity such as pressure ionization, Stark broadening and ion-ion coupling. The second short pulse beamline will be used to diagnose these high density plasmas using high energy X-ray backlighting and Thomson scattering. Orion will also be used to carry out experiments in hohlraums to measure the properties of lower density plasma heated by X-radiation using techniques tried and tested over several decades of experiments on HELEN and US lasers.

In addition to these programmatic areas AWE is working with the academic community in areas such as Inertial Confinement Fusion (ICF). The Centre for Inertial Fusion Sciences (CIFS) has been established at Imperial College, London to provide a means for AWE to interact with and contribute to, ICF and HEDP work in the international academic community (e.g. HiPER) and to facilitate academic access to Orion.

Plasma Diagnostics

Orion has a broad range of plasma diagnostics (optical, X-ray and particle) within the scope of delivery of the project. These fall in to two main categories: those that are permanently installed and those which are removable – deployed using a transfer system called a Ten Inch Manipulator (TIM).

The permanently installed optical diagnostics cover PASBO (Passive Shock Breakout), ASBO (Active Shock Breakout), Velocity Interferometer System for Any Reflector (VISAR), Pyrometry and Probe beam detection. Together with time resolved full aperture SRS/SBS Backscatter Long Pulse, Short pulse and NBI (Near-backscatter optical imaging). X-rays are measured using: a Dante (Soft (100eV – keV) X-ray diodes); Filter Fluorescer (20-100 keV X-ray detector); KB X-ray Microscope (time integrated imaging at a few keV with 10 micron resolution); a hard X-ray spectrometer (100keV – 2MeV X-ray detectors) and a Transmission Grating Spectrometer (absolutely calibrated time resolved or time integrated X-ray diagnostic 120eV – 1.2keV). Particles are measured using a high energy (50MeV - 1GeV) electron spectrometer and neutron diagnostics (nToF and Total Yield).

The TIM, shown in Figure 2, is the standard system used on Orion for inserting and retrieving a target diagnostic payload into and out of the target chamber without the need to let the target chamber vacuum up to air. The TIM system provides support services to the diagnostic payload and includes a turbo molecular vacuum pump and isolating valve so that the target chamber vacuum is unaffected when the payload is deployed. The TIM carrier or “boat” will be used to carry a range of different types of diagnostic assemblies consisting of various types of sensors and instruments.

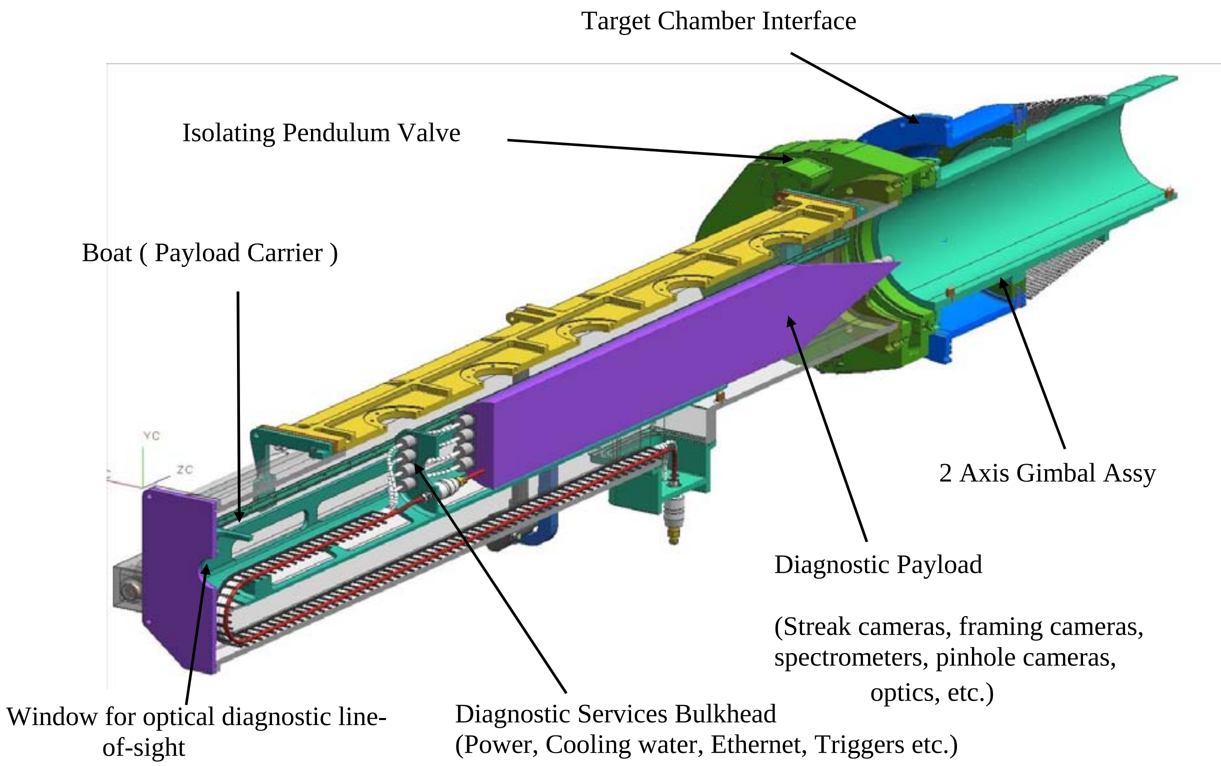

Figure 2: Ten Inch Manipulator (TIM) for deploying target diagnostics on Orion

The TIM based diagnostics include: three Gated X-ray Detectors (100eV – few keV with pinhole camera array providing <100ps gating capability); four X-ray streak cameras (with imaging snout and crystal spectrometer providing ps and sub-ps resolution 100eV – few keV); X-ray crystal spectrometers; an XUV Grating Spectrometer (time integrated or time resolved measurements 1–40nm) and the ability to deploy TLDs (measuring hard X-ray dose 0.1–20MeV). The ion diagnostics include a Thompson Parabola (proton spectra 0.1–10MeV); Faraday Cups (charged particle temporal profile measurement) and the ability to use CR39 and radiochromic film for charged particle dose and emission profile measurements.

Conclusions

The Orion facility provides a combination of two short pulse (Petawatt) and ten long pulse beams for material properties studies in novel High Energy Density regimes. The academic community will be given access to the wide range of diagnostics that the facility can offer. Multiple beam test firing programme is now in progress. The first experiments to look at materials properties in the high temperature, high density regime will commence in the spring of 2012.