Tunable UV Upgrade on OMEGA EP

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Controlled experiments are necessary to test and refine simulation tools for the mitigation of cross-beam energy transfer (CBET) in direct-drive laser-driven inertial confinement fusion using wavelength detuning.[1–3] To this end, experiments have been proposed at the Omega Laser Facility that feature a wavelength-tunable UV beam coupled into the target chamber of the 60-beam OMEGA laser (via the P9 port). The new capability is referred to as the tunable OMEGA P9 (TOP9) beam. These experiments will characterize the interaction of the tunable beam with one or more fixed-wavelength beams from the 60-beam OMEGA Laser System as a function of wavelength detuning, polarization, and interaction angle. The top-level requirements for the tunable UV beam are dictated by the experimental needs and are listed in Table I.

Table I: Top-level system requirements for the tunable UV beam for CBET mitigation experiments.

Parameter	Minimum requirement	Goal
Wavelength-tuning range	350.2 to 353.4 nm	
Wavelength step size	≤0.1 nm	
UV power on target	0.1 TW (351 nm to 352.6 nm) 0.01 TW (350.2 nm to 353.4 nm)	0.5 TW for pulses ≤1 ns 0.1 TW for pulses ≤2.5 ns (full tuning range)
Polarization	(1) linear, direction rotatable over 2π (2) random (distributed polarization rotator)	

An OMEGA EP beamline[4] was chosen in order to leverage both the short- and long-pulse capabilities of the OMEGA EP beamline, as illustrated in Fig. 1. The TOP9 system utilizes the short-pulse optical parametric chirped-pulse–amplification (OPCPA) front end to take advantage of the spectrally broad gain in the optical parametric amplification (OPA) process. For the TOP9 system, the OPCPA front end is converted into a tunable OPA system by replacing the chirped broadband seed laser with a tunable narrowband laser.[5] The pulses are then injected into the OMEGA EP beamline for amplification to the >100-J level. The TOP9 system also takes advantage of the existing long-pulse UV infrastructure of the OMEGA EP beamline, with the frequency-conversion crystals (FCC's) providing frequency tripling, and suites of laser diagnostics characterizing the laser performance at each stage.

A beam transport system (see Fig. 2) was designed and built to transport the UV beam through the shield wall between the OMEGA EP and OMEGA Laser Bays, where it is directed into the P9 port of the OMEGA target chamber and focused to target. The OMEGA EP periscope features a retractable lower mirror to intercept the TOP9 beam after the FCC. A vacuum image relay limits beam degradation caused by diffraction and reduces the UV beam path in air. A new platform was built onto the north-end mirror structure in the OMEGA Target Bay to support the image relay and other associated optics, including an insertable distributed polarization rotator or a rotatable half-wave plate, the combination satisfying the system's polarization control requirements.

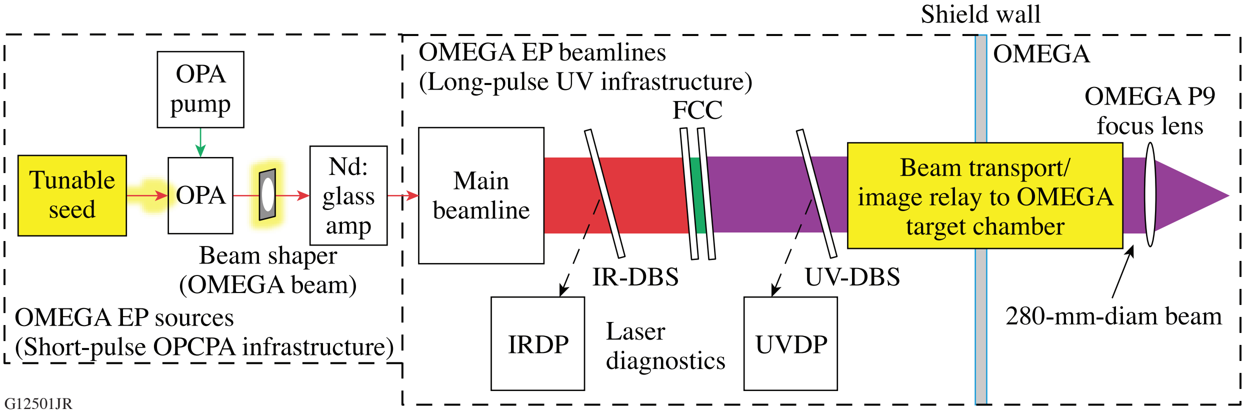

Figure 1
High-level diagram of the TOP9 OMEGA EP beam with upgraded elements highlighted in yellow. (OPA: optical parametric amplification; OPCPA: optical parametric chirped-pulse amplification; IR-DBS: infrared diagnostic beam splitter; IRDP: infrared diagnostics package; FCC: frequency-conversion crystals; UV-DBS: ultraviolet diagnostic beam splitter; UVDP: ultraviolet diagnostics package).

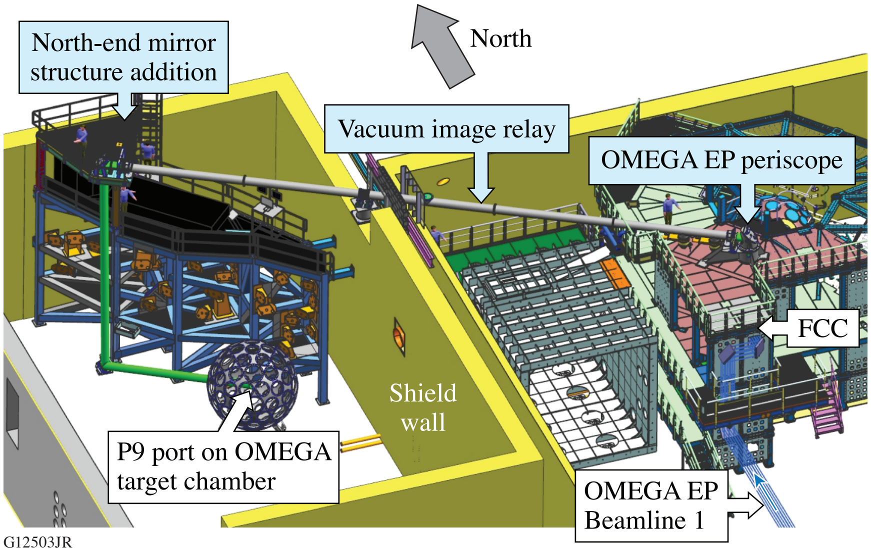

Figure 2
Solid-model drawing of the TOP9 transport system with key features indicated.

The performance envelope (plotted in Fig. 3) defines the range of pulse durations and energies that can be delivered with the tunable UV beam; it was developed based on consideration of a number of limiting effects. For short-duration pulses, the UV power is limited by concerns over small-scale self-focusing caused by the nonlinear Kerr effect in the transmissive optical materials (ΣB), comprising the TOP9 transport system and final optics.[6] For longer-duration pulses, the performance is limited by the development of transverse stimulated Brillouin scattering (SBS) in the optics.[7] Shots to the OMEGA EP target chamber allow for higher energies as a result of a larger beam size available, fewer transmissive optics in the transport path, and proximity to the target chamber.

The TOP9 beam has been commissioned to the OMEGA target chamber. The full-beam small-signal net gain as a function of wavelength was measured using a series of shots to a full-aperture calorimeter at the output of the transport spatial filter. The laser system produces the required 1ω energy at the extreme wavelengths by pumping up to 9 of the 11 main amplifier disks that are available in the OMEGA EP beamline. Longitudinal chromatic aberration in the beamline was measured and found to be corrected to $<\lambda/20$ by OMEGA EP's diffractive color-correcting injection lens. Near-field beam quality has been measured to be consistent with standard OMEGA EP performance.

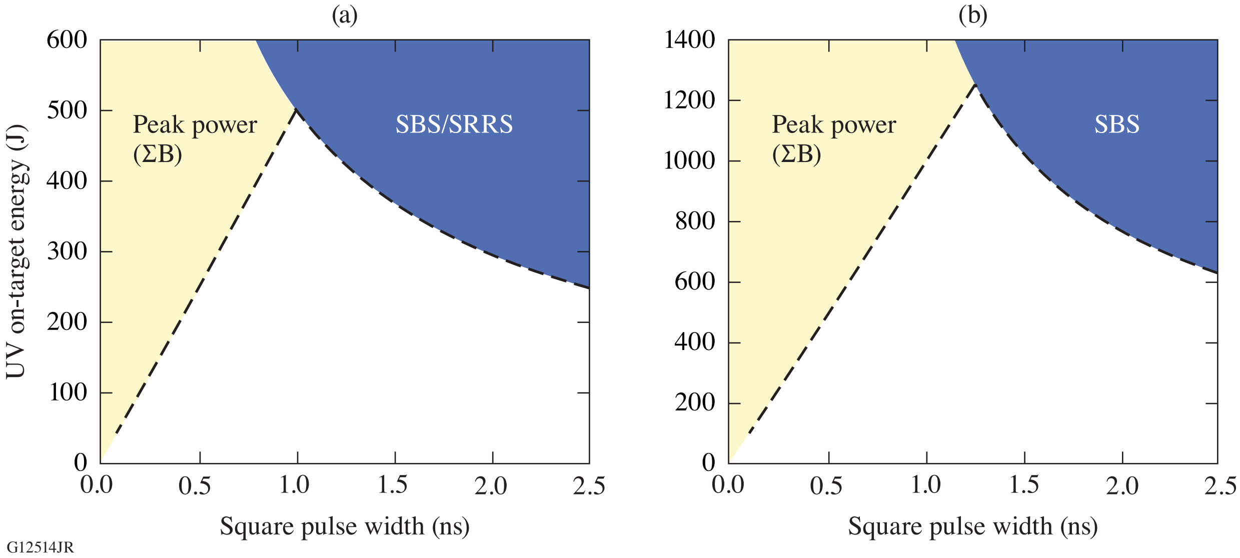

Figure 3
Performance envelope (maximum on-target energy versus square-pulse duration) for tunable UV shots to (a) the OMEGA target chamber (28-cm-diam round beam) and (b) the OMEGA EP target chamber (36-cm-sq beam). SRRS: stimulated rotational Raman scattering.

Pulse shaping is yet another active area of development. To maintain stability, the OPA is operated in saturation, which renders the creation of arbitrary pulse shapes difficult. Current pulse shapes are square at the output of the front-end OPA stages and tend to be distorted because of gain saturation in the downstream Nd:glass amplifiers and nonlinear frequency conversion. Nevertheless, arbitrary pulse shaping has been demonstrated in a laboratory prototype,[5] and it is a goal to provide arbitrarily shaped pulses with tailored ramps, steps, and other features that are currently available with the standard front ends of both OMEGA and OMEGA EP.

Construction of the tunable UV system was completed in May 2018, and commissioning of the system to the OMEGA target chamber was completed in June 2018. To date, the system has performed well in four experimental campaigns that studied CBET and other laser–plasma interactions, and it will enable future experiments that will advance the effort to mitigate CBET.

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