# A Transmitted-Beam Diagnostic for the Wavelength-Tunable UV Drive Beam on OMEGA

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Understanding how light propagates through plasma is of great importance in many fields of physical science. In the absence of a critically dense surface, the majority of light incident into a plasma will pass through with little perturbation. Yet, much can be learned about the plasma by studying the properties of light that transmits through it. Measuring the power, spectrum, and spatial profile of transmitted light provides a means to investigate a number of key laser–plasma interactions (LPI's) such as filamentation, laser absorption, and cross-beam energy transfer (CBET). Figure 1 shows a new experimental platform developed on the OMEGA laser to explore these processes.[1] A wavelength-tunable (350- to 353-nm) UV drive beam (TOP9) has been added to OMEGA's 61st beamline in port P9 (Ref. 2) and a transmitted-beam diagnostic (P9TBD), located in the opposing port P4, characterizes the properties of the TOP9 beam after it propagates through the plasma. Together, these capabilities support a range of experiments designed to validate and constrain plasma-physics models and CBET mitigation strategies.

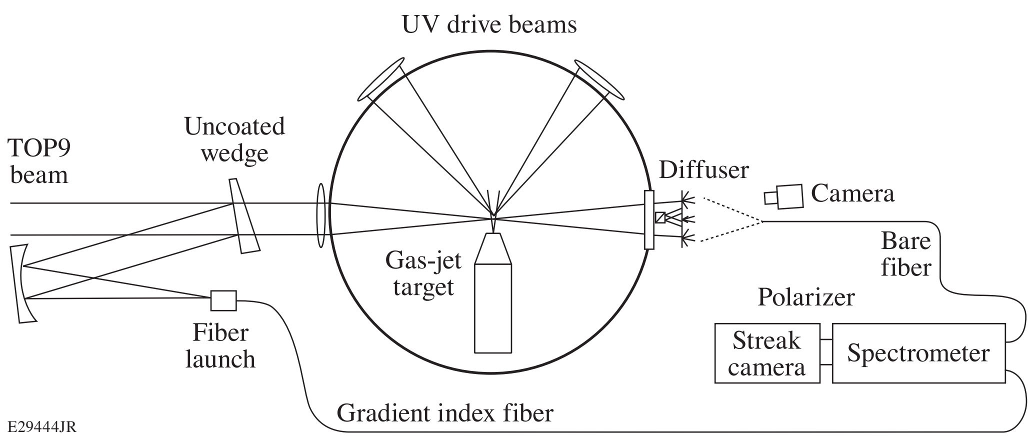


Figure 1
A charge-coupled–device (CCD) camera and fiber-coupled streaked spectrometer measure the energy, power, and near-field fluence of TOP9 after it transmits through an underdense plasma. The initial spectral power of the beam is also measured.

The P9TBD measures the energy, fluence, power, and spectrum of the TOP9 beam after it propagates through an undersense plasma. After passing through focus at target chamber center (TCC), the TOP9 beam expands and is projected on a semi-transparent diffuser. A fraction of the incident light transmits through the diffuser and forward scatters off the rear surface, generating an object that can be imaged. Internal scattering in the bulk of the 500-$\mu$m-thick diffuser limits the spatial resolution to 800-$\mu$m FWHM. Because the plasma and laser focus at TCC are small (~1 mm) and the diffuser is far away (1.9 m), a given position on the diffuser corresponds to the angle at which the light left the plasma. The vacuum window and diffuser have a 450-mm optical clear aperture that represents an *f*/4.2 angular field of view (Fig. 2). This allows one to observe plasma-induced refraction and filimentation[3,4] of the TOP9 beam beyond its native *f*/6.7 cone. A serviceable debris shield protects the thicker and more costly

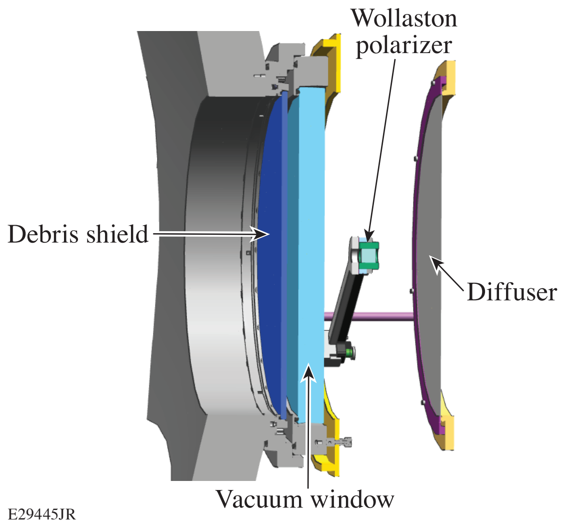


Figure 2
A cross-section view of the P4 port assembly. A 480-mm-diam debris shield protects the vacuum window and can be swapped prior to critical experiments to ensure nominal transmission through the optics. A Wollaston polarizer placed in front of the diffuser samples a 20-mm sub-aperture of the transmitted beam.

vacuum window from damage and particulate accumulation. The debris shield can be replaced prior to P9TBD experiments to restore nominal optical transmission. A Wollaston polarizer can be installed to measure the polarization of the central 20-mm subsection of the transmitted beam.

A CCD camera and imaging lens assembly is used to measure the time-integrated spatial profile of the transmitted beam (Fig. 3). The spectrally resolved power of the transmitted beam is measured using a fiber-coupled streaked spectrometer. A flat, cleaved optical fiber pointed at the center of the diffuser couples a spatially averaged sample of the incident light. The effective field of view at the diffuser plane is determined by the angular acceptance of the fiber optic. To improve sampling uniformity across the entire diffuser area, the fiber is positioned with a 3.5-m standoff distance, limiting the range of angles coupled to 0° to 3.8°. This also maintains the roll-off in sensitivity due to area foreshortening, which scales with $\cos^4(\theta)$, to a less-than-1% effect. The total power coupled into the fiber is given by $\Phi_{fiber} = \Phi_{in} \sin^2(\theta_{max}) A_f * T/A_d$, where $\Phi_{in}$ is the power incident on the diffuser, $T$ is the diffuser transmission (0.1), $A_f$ is the area of the fiber core (430-$\mu$m-diam core), and $A_d$ is the diffuser area.

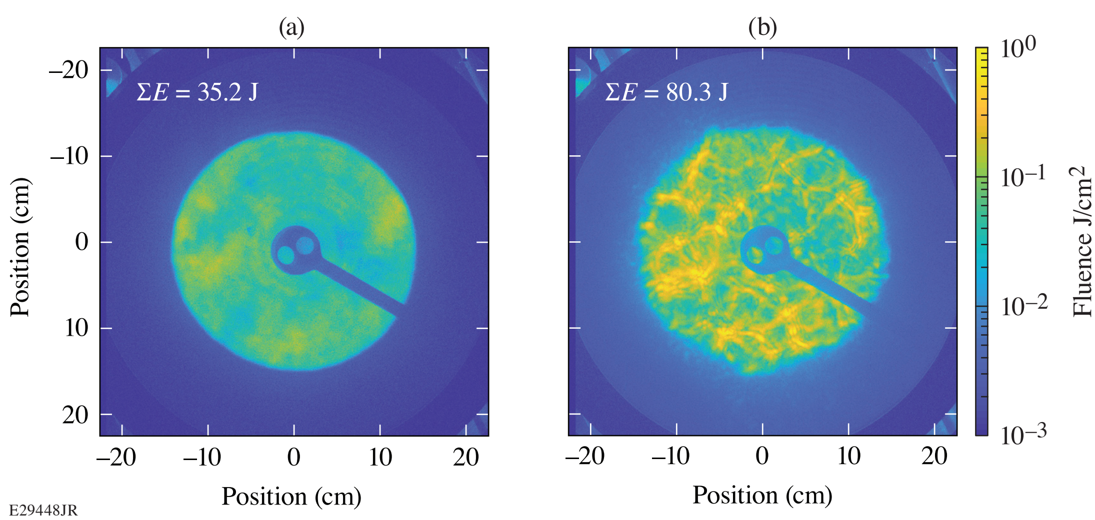


Figure 3
(a) The spatial profile of the TOP9 beam is imaged after terminating on a semi-transparent diffuser. The P9TBD instruments are photometrically calibrated to the laser system calorimetry by taking a blow-through shot with no plasma present at TCC. (b) The TOP9 beam refracted as it propagated through a preformed, underdense plasma. The spatial resolution of the recorded image corresponds to the angular distribution of energy that left TCC. In this experiment, LPI's produced high-frequency variations in the transmitted beam's intensity.

Together, this results in a coupling efficiency of ~$4 \times 10^{-10}$. This approach is lossy compared to an image relay but avoids issues with the high numerical apertures required to demagnify a large object onto a small fiber core.

The initial power and spectrum of the TOP9 beam are measured prior to entering the target chamber using a full-aperture, uncoated wedged optic located in front of the final focusing lens. The pickoff beam is focused into a dual-diffuser–based fiber launcher and is routed to the streaked spectrometer. Samples of both the input and transmitted beam are recorded simultaneously on the same streaked image using a custom-built multichannel fiber input head. The standard spectrometer entrance slit assembly is replaced with a V-groove array that positions up to 20 individual fibers in discrete locations offset horizontally along the axis of dispersion.

The P9TBD uses a 1.0-m-focal-length Czerny–Turner spectrograph (McPherson, 2061) and a 4320-grooves/mm grating that produces a linear dispersion of 8.0 mm/nm at the streak camera photocathode. A mask attached to the front of the V-groove array positions a series of laser-cut, vertical slits in front of each fiber face, allowing optimization of slit width for each channel. A typical streaked image, shown in Fig. 4, demonstrates P9TBD's ability to directly observe CBET, in this case from an OMEGA drive beam to the TOP9 beam. The temporal resolution of the streaked image is approximately 100-ps FWHM limited by contributions from optical path length differences from TCC to the fiber input, modal dispersion in the fiber transport, pulse-front tilt in the spectrometer, and streak camera temporal resolution.

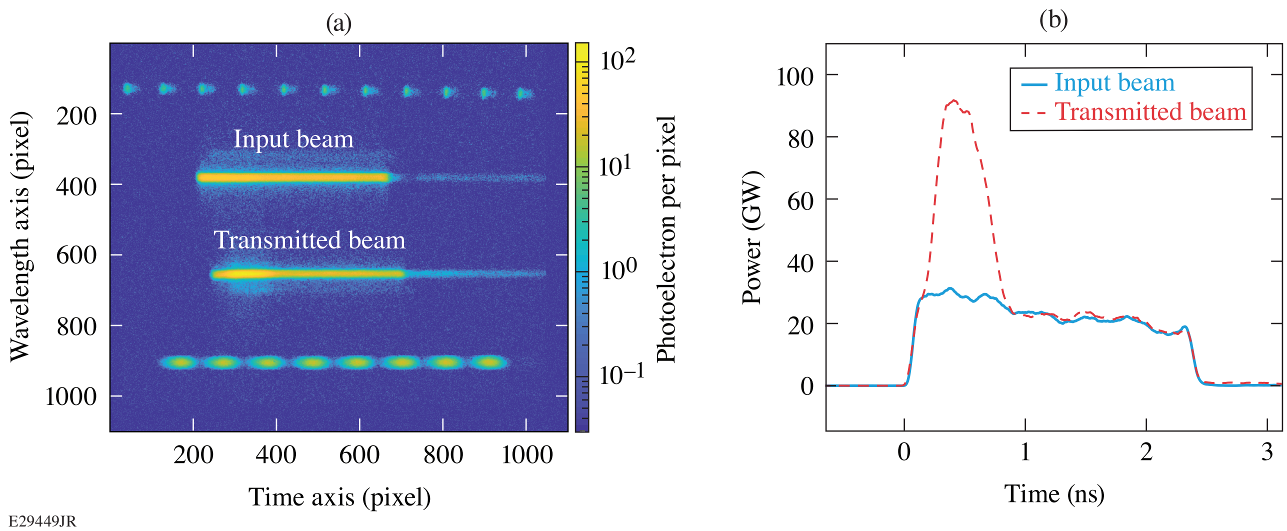


Figure 4
(a) An example of the raw data produced by the streaked spectrometer. For this shot, both channels used 500-$\mu$m slits to maximize measurement of the dynamic range. At peak power, a 100-ps time bin contains approximately 40,000 photoelectrons. (b) Cross-beam energy transfer can be measured directly by comparing the input and transmitted power of the TOP9 beam. In this experiment, a 500-ps, 0.4-TW OMEGA beam interacted with the TOP9 beam in a preformed plasma, producing 27 J of energy transfer.

The P9TBD instruments are cross-calibrated, in absolute terms, to the OMEGA EP Laser System's calorimetry by taking a full-energy shot with no plasma present at TCC [Fig. 3(a)]. This generates a calibration factor relating the total energy that leaves TCC to the total ADU's in the CCD and streaked image. Fluence and power can then be determined from the image magnification and sweep rate.

Understanding and managing LPI processes are necessary to produce deterministic and reliable plasmas. The next generation of fusion class lasers will likely make use of broadband ($\Delta\omega > 1\%$) or multicolor drive beams to mitigate CBET. TOP9 and P9TBD provide experimental access to this parameter space and a means to validate advanced LPI models. Terminating the transmitted beam onto a semi-transparent diffuser enables an imaging CCD camera and fiber-coupled streaked spectrometer to characterize its spatial profile, polarization, power, and spectrum.

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