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A pulsed-laser calibration system for the laser backscatter diagnostics at the Omega laser

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A calibration system has been developed that allows a direct determination of the

sensitivity of the laser backscatter diagnostics at the Omega laser[1]. A motorized mirror at

the target location redirects individual pulses of a mJ-class laser onto the diagnostic to

allow the in-situ measurement of the local point response of the backscatter diagnostics.

Featuring dual wavelength capability at the 2nd and 3rd harmonic of the Nd:YAG laser,

both spectral channels of the backscatter diagnostics can be directly calibrated. In

addition, channel cross-talk and polarization sensitivity can be determined. The

calibration system has been employed repeatedly over the last two years and has enabled

precise backscatter measurements of both stimulated Brillouin scattering and stimulated

Raman scattering in gas-filled hohlraum targets that emulate conditions relevant to those

in inertial confinement fusion targets.

52.40.Nk, 52.58.Ns

Introduction

In the indirect-drive approach to inertial confinement fusion the deuterium-tritium fuel is compressed by the ablation pressure of soft x-rays inside a laser-heated high-Z cavity (hohlraum)[2]. This requires intense laser pulses at wavelengths of the 2nd or 3rd harmonic of Nd:glass to propagate over distances of several mm before depositing their energy into the hohlraum wall. Parametric laser-plasma instabilities in the hohlraum plasma can backscatter significant fraction of the laser light by e.g. stimulated Brillouin scattering (SBS) and stimulated Raman scattering (SRS) resulting in reduced efficiency and radiation symmetry. The study and understanding of these processes is thus important to the success of inertial confinement fusion.

In recent years, the understanding of laser-plasma interactions has made significant advances[3]. These measurements require an accurate measurement of laser backscattering from the targets. At the Omega laser two of the 60 beams are equipped with comprehensive backscatter stations comprising each a Full-Aperture Backscatter Station (FABS) and a Near Backscatter Imager (NBI). Light that is backscattered into the final focusing lens aperture is separated from the incoming beam path by a full aperture uncoated glass wedge and down-collimated into the FABS, measuring energy and time-resolved spectra. The NBI measures the energy of the light backscattered outside the focusing lens. This light is diffusely scattered by Spectralon® (Labsphere) coated plates surrounding the beam aperture and an image is recorded with a CCD camera. Both FABS and NBI cover two separate spectral ranges of 351±10 nm and 400-700 nm, respectively.

In this paper we describe a calibration system that was developed to calibrate the energy response of this diagnostic in order to enable accurate absolute measurements of the backscattered energy.

Description of the calibration system

The approach to the backscatter calibration system is to use a dedicated pulsed laser to measure in-situ the total transmission of the optical path through the FABS, as well as the local point response (sensitivity) of the NBI system. This approach was successfully applied to calibrate the NBI during the NIF early light campaign[4]. A schematic of the pulsed laser calibration system is shown in fig. 1. The system employs a commercial pulsed Nd:YAG laser (Minilite II, Continuum, Inc.) capable of delivering pulses of 3-5 ns duration and energies of up to 25 mJ at the 2nd harmonic (532 nm) and 8 mJ at the 3rd harmonic (355 nm). This allows calibration measurements in both spectral ranges of the diagnostics. A fixed fraction (~10%) is reflected by a plane-parallel un-coated glass plate
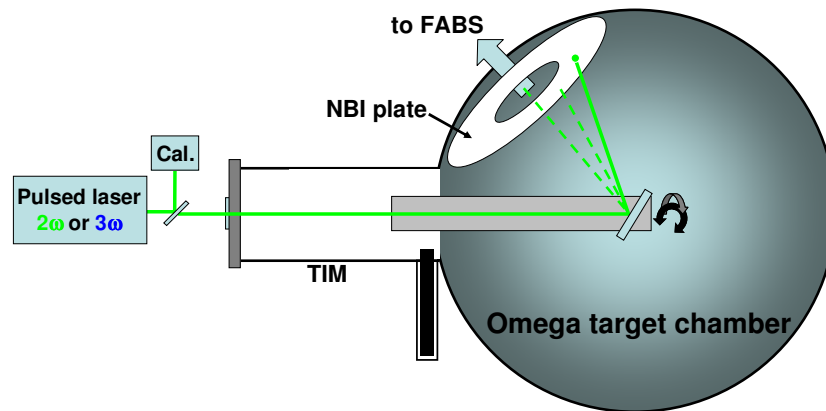

Fig. 1: Schematic of the backscatter calibration system. The pulsed laser is injected through the TIM and the beam is deflected from the target chamber center onto the backscatter diagnostics.

onto an energy sensor, allowing the energy of each individual pulse to be measured. The beam is injected into the target chamber through a UV-grade Fused Silica window in the back end of one of Omega's ten-inch-manipulators (TIM). The TIM is loaded with an extension carrying a motorized mirror mount which is driven to the center of the target chamber. A 2"-diameter mirror steers the laser beam from the target chamber center onto the NBI scatter plates and into the FABS aperture, respectively.

Having the calibration beam originate from the actual target location is required to propagate the beam down the FABS optical path. Also, this way the NBI response is measured with the beam incident on the scatter plates at the same angle as the backscattered radiation to be measured. While newly refurbished NBI plates have a near ideal Lambertian angular scattering characteristic, older plates that have accumulated a certain amount of target debris, are expected to exhibit a strong component of specularly reflected light, making calibration measurements with the calibration light coming from the actual target location mandatory.

By steering the beam onto a dedicated absolutely calibrated calorimeter the pick-off energy sensor is cross-calibrated.

Calibration measurements

NBI calibration

The NBI is calibrated by sending individual pulses onto the NBI plate and acquiring an NBI image with the same configuration as on a real target shot. The motorized mirror is used to scan the calibration laser spot across the plate to measure the spatial variations in the sensitivity. Of order 100 shots are used for a typical calibration run. Fig. 2 shows a
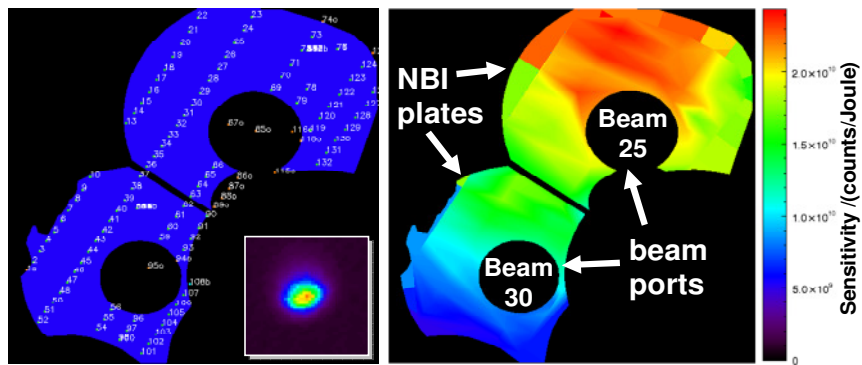
Fig. 2: (left) Shot locations on the NBI plate from a calibration run. The insert show a typical spot from the calibration laser. (right) Sensitivity map for the SRS channel.

typical result from a calibration run. The calibration laser produces a ~15 mm diameter spot on the NBI plate, corresponding on average to ~10 pixel in the NBI image. An automated post-processing software locates the spot in each image. Various consistency checks are performed to verify that the spot was correctly recognized and to discard e.g. saturated or clipped laser spots. Then, the local background is subtracted and the total number of counts in the spot is normalized to the laser pulse energy of the respective shot, yielding the local point response (unit counts/Joule). Bi-linear interpolation is used to generate a continuous sensitivity map. The absolute accuracy in the determination of the point response is limited by the absolute calibration of the calorimeter used to cross-calibrate the pick-off energy sensor, and is estimated to ±5%. The relative shot-to-shot reproducibility is approx. ±1%, limited by the shot-to-shot accuracy of the pick-off energy sensor. Error due to camera noise is negligible, as the background RMS is <2 counts, compared to the average signal of ~500

counts/pixel over ~100 pixel.

At the Omega laser, more than 1000 target shots are delivered per year, with targets varying greatly in total mass and materials. This results in a considerable amount of target debris deposited on the NBI plates. As a consequence, the plates are exchanged approx. twice per year. We have performed NBI calibrations on several plates and at various times during the lifetime of the plates. Fig. 3 shows the sensitivity in the short-wavelength channel (at 355 nm) over a period of 200 days. The calibrations were performed on various plates and at various instances within their time of usage. We find that the sensitivity decreases significantly as function of time since replacement. A simple model that assumes that debris is deposited at a constant rate of areal density $1/\tau$ on the plate and that the sensitivity of the plate when completely covered with debris
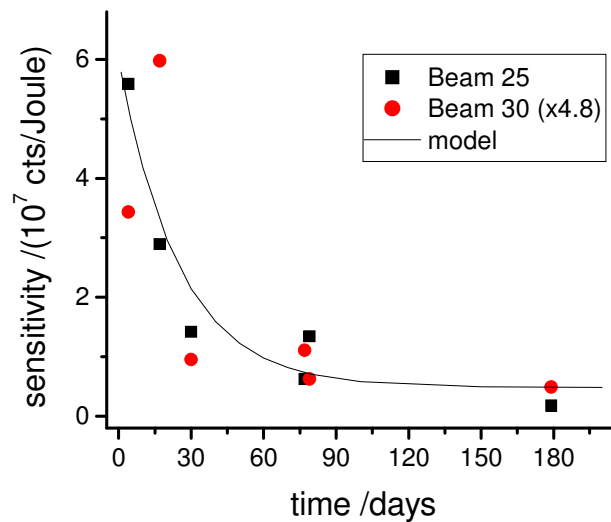

Fig. 3: Variation of NBI sensitivity (at 355 nm) with time from last plate change. The sensitivity drops by over 90% over a few months. The lower sensitivity of Beam 30 is due to the oblique viewing angle of the NBI cameras.

decreases to a fraction of δ of the initial sensitivity S_0, results in the sensitivity decreasing with time as

$$S = S_0\left[(1-\delta)\cdot \exp\left(-\tfrac{t}{\tau}\right)+\delta\right].$$

The rate $1/\tau$ will depend strongly on the frequency of target shots and the amount/mass of target material per shot, while δ will depend on the target materials used. We find that the calibration data can be reasonably well fitted with $\tau \sim 30\ldots40$ days and $\delta \sim 0.02\ldots0.1$. For the long wavelength channel (400-700 nm) we also find a strong decrease in sensitivity over time, the available data is consistent with the same values for the fitting parameters τ and δ. This shows clearly that only a fairly recent calibration ensures that accurate energy measurements can be performed with the NBI.

Debris on the NBI-plates is a potential source of cross-talk from the short to the long wavelength channel, e.g. due to fluorescence in the 400-700 nm spectral range. By acquiring NBI images on the long wavelength channel while running the calibration laser at 355 nm we measured a cross-talk of 3×10^{-5} on a NBI plate that had been in use for ~80 days. This amount of cross-talk is completely negligible as it is far below the detection threshold of the diagnostics. However, we note that the fluence of the calibration beam on the NBI plates is only ~5 mJ/cm^2. In a typical experiment, the UV fluence on the NBI plates can reach values of order 100 mJ/cm^2, a level at which fluorescence and therefore cross-talk might be considerably stronger.

FABS calibration and polarization sensitivity

In the short wavelength channel the FABS is usually calibrated using the Omega laser itself, by firing the opposing 351 nm beam with an energy of 10-30 J into the FABS

aperture. However, the final turning mirrors do not transport unconverted 2w light, which could be used to calibrate the long wavelength channel. We therefore used the pulsed-laser calibration system for an in-situ measurement of the transmission of the FABS optical path at 532 nm. Pulses of ~20 mJ energy were sent from the target chamber center into the FABS, and the transmitted energy was measured by an absolutely calibrated energy sensor (J9LP, Coherent Inc.). We measured the transmission to $(2.9\pm0.3)\times10^{-3}$. The error is dominated by the absolute calibration of both the energy sensors after the motorized mirror and at the end of the FABS beam path. The measured value lies ~20% below a simple estimate of the FABS transmission using the properties of the individual optical components. The measured transmission, together with the optical-to-electrical calibration factor of the FABS calorimeters, yields the FABS calibration.

Using a half-wave plate at the exit of the calibration laser we varied the beam polarization to determine the polarization dependence of the FABS transmission. At 532 nm, the transmission was maximized at the polarization of the incoming Omega target beam, with a 2:1 ratio to the perpendicular polarization. This effect is most likely dominated by the reflectivity of coating of the final turning mirror, which is optimized for a wavelength of 351 nm. As expected, using the calibration laser at the 3rd harmonic showed no polarization dependence of the FABS transmission.

Operation

Fig. 4 shows data from the NBI obtained in an experiment studying the hohlraum energetics employing multiple-ion species plasmas[5]. In these shots the hohlraum gas composition was varied to study the effect of ion Landau damping on laser backscatter.
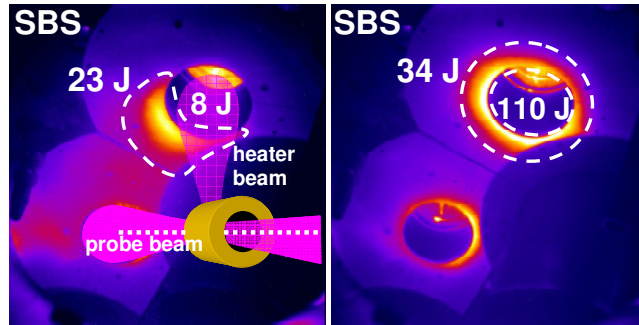
Fig. 4: NBI data in the short wavelength channel, showing strong backscatter from Stimulated Brillouin Scattering. The sketch shows the alignment of the hohlraum using one beam as on-axis probe beam. The energies measured by FABS and on the NBI plates are denoted in the image.

The images demonstrate the range of energies covered by NBI. For the probe beam the energy onto NBI is only about 0.05…0.1x the energy into FABS. The heater beam however encounters higher electron densities and gradients and thus shows significant beam spray and deflection, resulting in energies of 0.3x up to even 2x the energy in FABS. An accurate NBI calibration is therefore mandatory to reliably measure backscattered energies.

Acknowledgements

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