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COMMISSIONING EXPERIMENTS ON THE 100 TW SANDIA LASER *

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Abstract

We present results from laser-target interaction experiments performed within the 100 TW facility at Sandia National Laboratory. A series of K-alpha images of 25µm thick copper foils reveal an average K-alpha spot diameter of ~70±10µm and a pointing error of less than 50µm in both the vertical and horizontal directions. 2 omega optical probe pulse shadowgraphy images show front surface plasma growth and transverse focal structure from self-emission. Stacks of radiochromic film (RCF) positioned along the rear normal to the Cu foil indicate an average peak proton energy of 8±2 MeV.

I. INTRODUCTION

Numerical studies [1] suggest that the scheme of fast ignition requires ~18kJ of ~1MeV electrons be deposited into a 25µm diameter in a period of 20ps. It is also known that the temperature and transport of laser produced fast electrons within a target can be strongly affected by the amount of pre-plasma and thus the amount of laser pre-pulse energy. With such stringent requirements of energy deposition and such strong sensitivities to pre-pulse amplitude, it is necessary in the study of fast ignition to accurately characterize the associated laser parameters.

In the following, an experiment in which a series of 19 targets were shot as part of the commissioning phase for the 100 TW module of the Z-PW laser will be discussed. The principle goals of the experiment were to quantify the laser pointing stability, K-alpha spot size and pre-pulse effects of the Z-petawatt (Z-PW) laser through its interaction with 25µm thick copper foils placed at the laser focus.

II. DIAGNOSTIC LAYOUT

The laser-target interaction configuration, as shown in figure 1, consisted of a 25µm thick Cu foil at target chamber center situated with its normal at 45° to the incident 1.053µm short pulse laser. With an average laser energy of 21±6J, a typical pulse duration of ~3ps and a typical laser spot diameter of ~13µm, the laser intensity averaged to ~6×10^{18} W/cm^2.

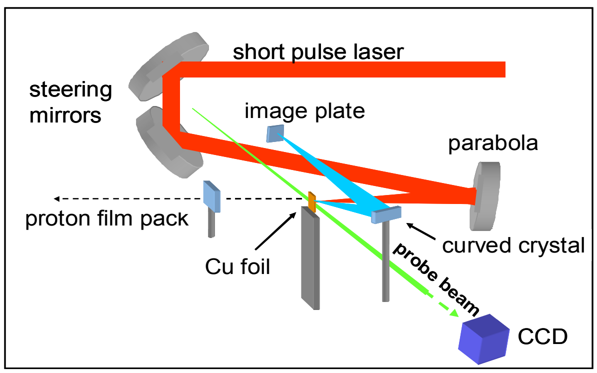

Figure 1. Laser/diagnostic configuration within the Z-PW chamber

Note that the associated laser power of 7×10^{12}W falls short of the 100TW mark during this period of commissioning by design and will eventually ramp to the full power

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As shown in figure 1, the layout consisted of three diagnostics set to observe the results of the laser pulse interaction with the front surface of the foil.

A. K-alpha Imaging Diagnostic

The primary diagnostic [2] was positioned behind the foil to image Cu K-alpha emission resulting from laser produced fast electrons within the target. As shown in figure 2, this diagnostic consisted of a spherically curved SiO_2 crystal x-ray optic and Fujifilm BAS-SR image plates for detection. The Cu K-alpha images were used to provide information on shot to shot variations in K-alpha spot size, intensity and position.

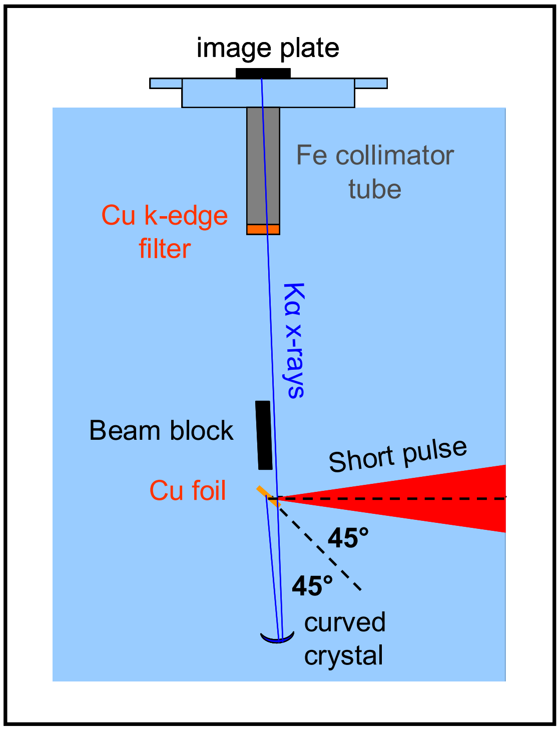

Figure 2. Plan view of the K-alpha imaging diagnostic configuration.

The curved imaging crystal was located in the horizontal plane 45° from the target rear surface normal and rotated to Bragg reflect the 8keV monochromatic Cu K-alpha emission onto the image plate. This imaging configuration provided 7.1x magnification and a 3.5mm field of view. Including the effects of spherical aberration, astigmatism, and an effective 3.5μm detector pixelation, the imager resolution was calculated to be 5.6μm. The actual resolution, which includes crystal mosaic and asphericity effects, and slight defocusing, is more like ~15μm [3].

A $1cm^2$, 19cm long, plastic-lined iron beam block placed between the target and the image plate was used to block direct radiation from the source. A 20cm long, plastic lined iron collimator was placed against the image plate to shield against background x-rays and bremsstrahlung producing electrons. A Cu K-edge filter covered the collimator entrance and further selected the 8keV K-alpha radiation. Small magnets were mounted within the collimator to deflect electrons from the field of view.

B. Shadowgraphy Diagnostic

A variable delay 2 omega (526nm) short pulse optical probe beam was set up and aimed to pass along the front surface of the Cu foil and onto a CCD camera for the purpose of front surface plasma shadowgraphy. This shadowgraphy configuration (shown in figure 3) enabled shot-to-shot monitoring of the laser pulse spatial profile and front surface plasma formation.

The 2 omega probe beam was compressed separately from and delayed relative to the 3ps interaction pulse to provide a 300fs exposure time arriving from 0 to 240ps after the 3ps long interaction pulse.

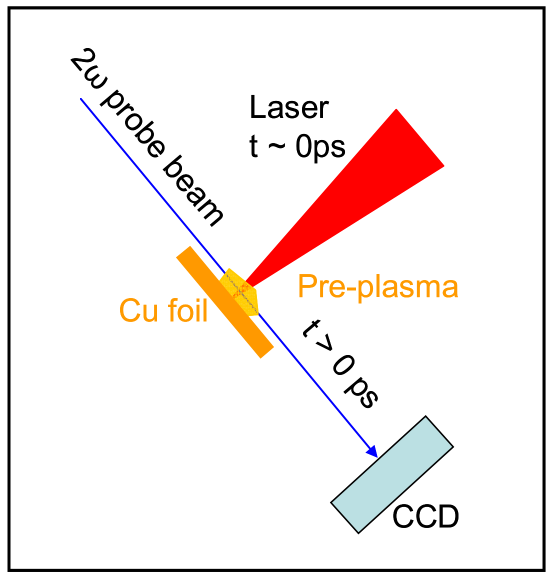

Figure 3. Schematic of shadowgraphy setup. The short pulse arrives and interacts with the target (t=0ps). The probe beam then passes through the interaction region (0ps < t < 240ps) and onto the CCD.

C. Radiochromic Film Stacks

For each shot, a stack of radiochromic film (RCF) was placed along the rear surface normal of the foil at a distance of 2-3cm to detect proton emission (see figure 1). As shown in figure 4, a film stack consisted of 7 to 10 layers of GAFCHROMIC radiation sensitive imaging film (two layers of HD-810 in the front for the higher proton doses followed by 5 to 8 layers of MD-55 for the more energetic protons). From these stacks, rear surface maximum proton energies could be estimated by comparison of the maximum penetration depth (in layers) to the known range for protons of a given energy passing through the RCF.

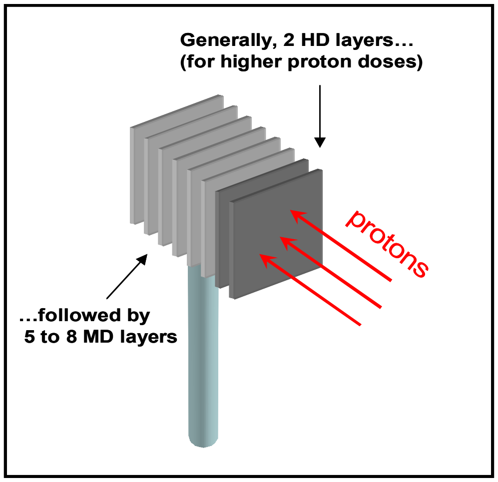

Figure 4. Composition of a typical RCF stack used for detection of rear surface proton emission.

III. METHOD AND RESULTS

A. Measuring Spot Sizes

It is known from past experiments [4] that K-alpha spot sizes are generally many times larger than the associated laser spot size and, at present, the connection between the two is not well understood so the following is not a direct measure of laser spot size variation but it does, however, represent a measurement of the general experimental reproducibility and, more importantly, it represents the true diameter of fast electron energy injection which is relevant to fast ignition.

To measure the Cu K-alpha spot sizes, the image plate images (which read out in a logarithmic scale) were first converted to a linear scale and background subtracted. Figure 5 shows a typical K-alpha image of the Cu foil.

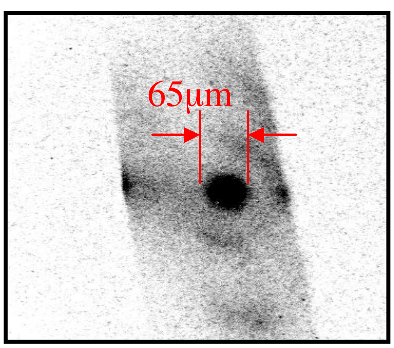

Figure 5. K-alpha image of a 25µm Cu foil viewed at 45° to the foil normal. FWHM spot size is ~65µm. The foil edges and the spot are illuminated in K-alpha.

Horizontal and vertical lineouts were taken through the centers of the K-alpha spots in the images. After correcting the x-axis for imager magnification, full-width, half-max (FWHM) measurements provided estimates of the spot sizes. Figure 6 shows the horizontal and vertical lineouts for the image of figure 5. The horizontal FWHMs were corrected for the 45 deg. view angle. Note from these lineouts the excellent signal to noise ratio (S/N) results ranging from 20 to 140 which were obtained. These high values were partly due to the 19cm Fe collimator which made at least an order of magnitude S/N improvement.

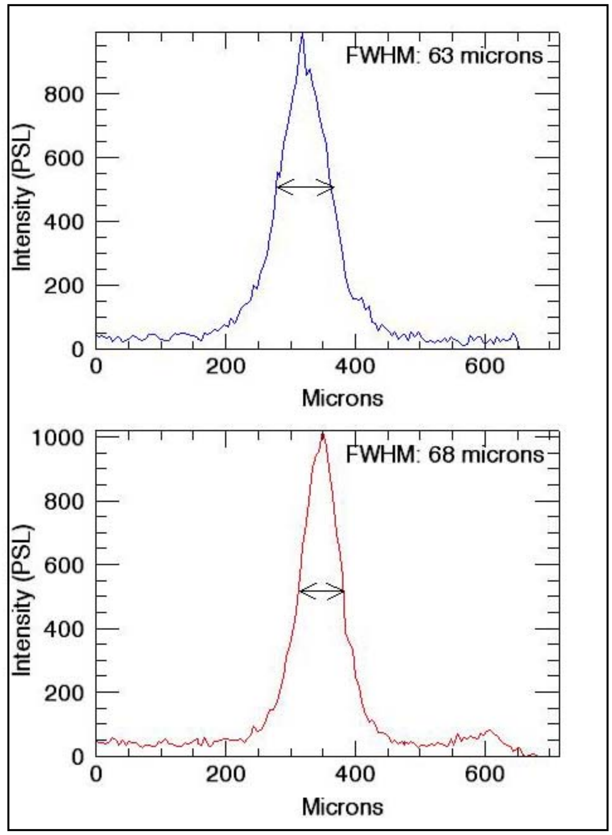

Figure 6. Vertical (top-blue) and horizontal (bottom-red) lineouts and associated FWHM values for the K-alpha image of figure 5.

In figure 7, the vertical lineout FWHM measurements are shown plotted against shot number. From these measurements, the vertical lineout FWHM averaged to 64±12µm. A similar result of 78±10µm was obtained from measurements of the horizontal lineout FWHM values. The FWHM measurement error of ±10µm was estimated as that resulting from the uncertainty of the peak count. Taking into account this measurement error contribution to the measured uncertainty in FWHM suggests that actual shot to shot K-alpha spot size variation was less than ±10µm.

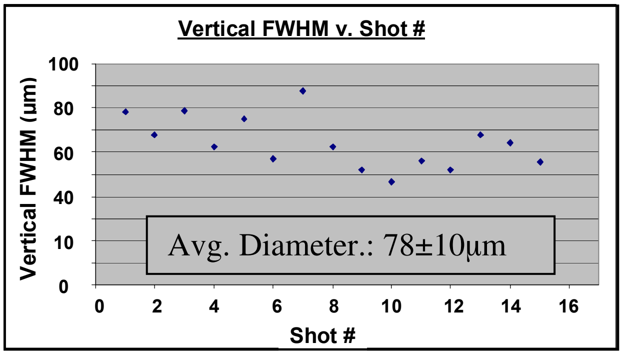

Figure 7. FWHM vertical lineout measurements plotted against shot number. A similar plot is produced for horizontal FWHM measurements.

B. Measuring Pointing Accuracy

The K-alpha imager provided shot-to-shot variations in laser spot position. With the target plane at 45° to both the laser and the crystal (see figure 2), a direct measure of pointing accuracy was obtained with the K-alpha images**.**

The shot to shot pointing accuracy was estimated from full vertical and horizontal lineouts in which the collimator edges were included for reference as shown in figures 8 and 9. The background levels of the lineouts were normalized and the profiles were aligned to the collimator edges with an accuracy of ±15µm.

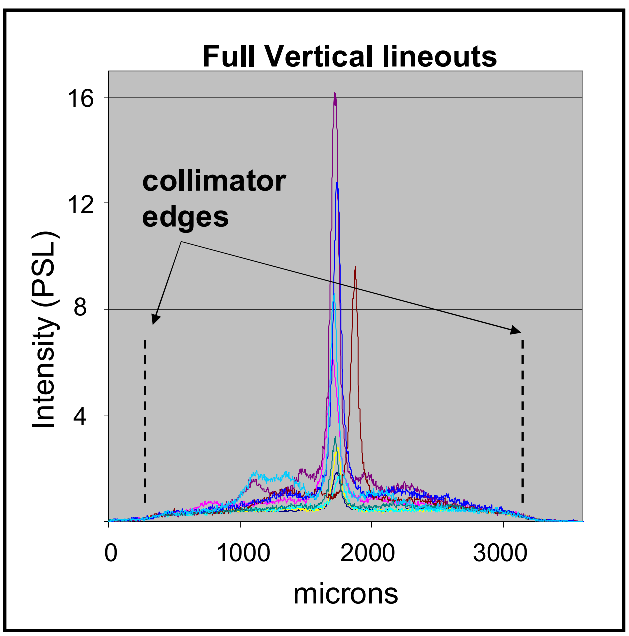

Figure 8. Full vertical lineouts of the K-alpha images. Backgrounds have been normalized and profiles have been aligned to the collimator edges.

The standard deviation of the vertical lineout peak positions is found to be 50.8µm. If the one deviant peak (of the 9 total) is excluded, this reduces to σ = 17.2µm. Comparing this 17.2µm with the 15µm alignment error indicates that the vertical laser pointing accuracy can be better than 17µm.

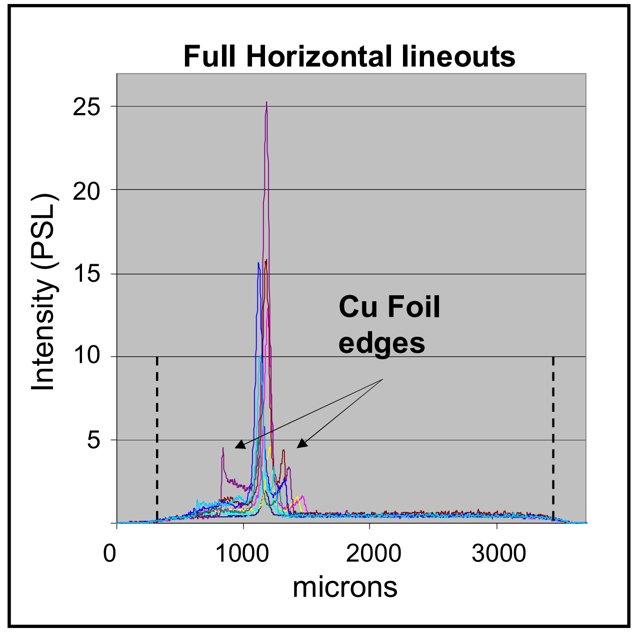

Figure 9. Full horizontal lineouts of the K-alpha images. Backgrounds have been normalized and profiles have been aligned to the collimator edges.

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For the horizontal pointing, the standard deviation of the peak position is 35µm. This is a larger variation than for the vertical peak position and may be due to a greater horizontal sensitivity to variation in target position. So while the vertical variation is due mostly to laser pointing accuracy, the horizontal variation is most likely a measure of the convolved accuracy of laser pointing and target alignment.

C. Front Surface Shadowgraphy

The 'shadowgraphy' diagnostic was used to monitor the laser pulse spatial profile and front surface plasma. In the timing series of shadowgrams shown in figure 10, the 25µm wide shadow of the Cu foil extends vertically across the image. In this transverse view, the laser comes in from the right.

Front surface plasma growth is apparent in this sequence of images. In the top image, the probe pulse arrives in coincidence with the interaction pulse and there is a small amount of surface plasma revealing the presence of a pre-pulse. At later times of 120 and 240 ps, there is seen to be a significantly larger region of surface plasma.

At 120 and 240ps, self-emission is seen at the laser focus. This self-emission may provide information about the transverse spatial structure of the laser focus. For example, the image at 120ps shows possible laser beam break-up.

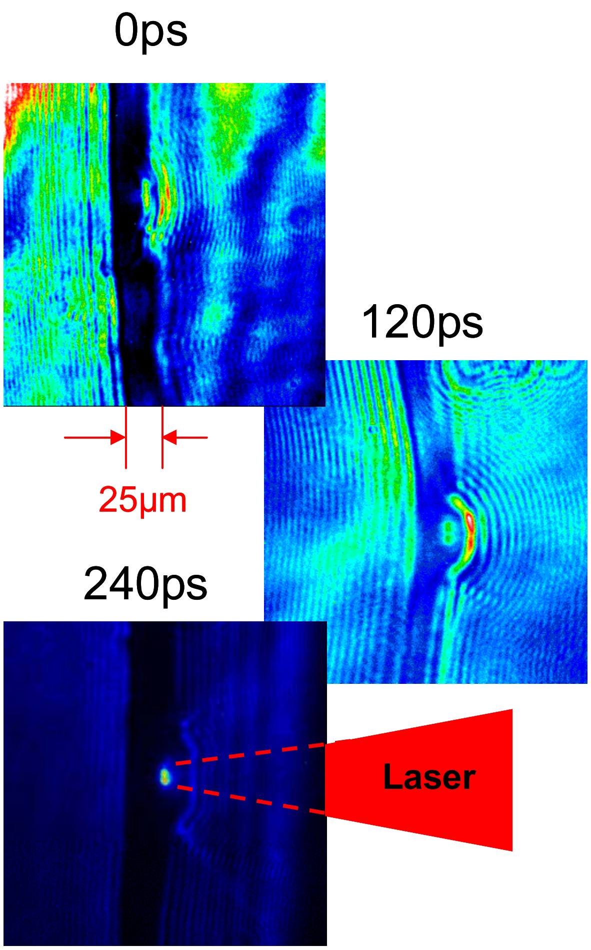

Figure 10. Transverse shadowgraph images of 25μm Cu foil at 0, 120 and ~240ps after arrival of 3ps interaction pulse. Note the apparent front surface plasma growth in this time sequence of images.

D. Rear Surface Proton Energies

As mentioned, the RCF stacks were used to characterize the energies of protons emitted from the rear surface. Rear surface maximum proton energies were deduced, as described above, from each of the series of radiochromic film (RCF) stacks giving an average maximum proton energy of 7.7±2.4 MeV [5]. While the shadowgraph at t=0 reveals the pre-pulse, such relatively high proton energies indicate that the pre-pulse was not sufficient to destroy the rear surface of the target.

These rear surface proton energies are expected to strongly follow laser energy variations and pre-pulse conditions [6]. Figure 11 shows a plot of these max energies against short pulse laser energy. As expected, there is a positive scaling with laser energy.

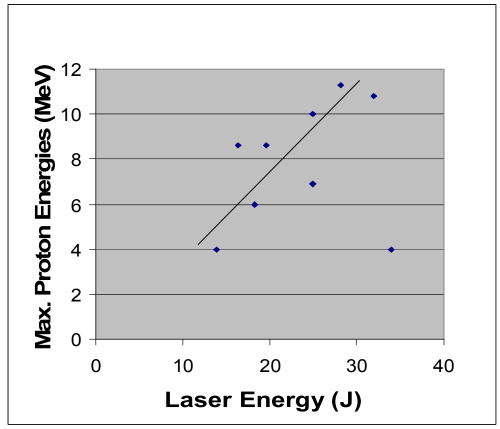

Figure 11. Plot of rear surface maximum proton energies versus laser energy shows strong positive scaling.

IV. SUMMARY

First Z-PW laser commissioning experiment has shown very good pointing and K-alpha spot size repeatability. FWHM shot to shot K-alpha spot size variation has been found to be less than ±10 μm. Shot-to-shot pointing accuracy has been found to be better than 15μm in the vertical direction and somewhat larger (<35μm) in the horizontal direction. Relatively large proton energies imply a clean short pulse beam. A 2 omega optical probe pulse produces good initial results as a shadowgraphy diagnostic. Specifically, a timing series has shown front surface plasma growth and self-emission shows some transverse laser focal structure.

V. REFERENCES

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