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Measurements of MeV Photon Flashes in Petawatt Laser Experiments

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DISCLAIMER

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in

Petawatt Laser Experiments

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ABSTRACT

Planar targets illuminated by the Petawatt laser system emit directed beams of photons with energies of MeVs. The laser pulses have durations of 0.5 or 5 psec, on-target energies in excess of 100 joules, and focal-spot sizes that vary from 10 to 100 µm, producing peak intensities greater than 10^{19} watts/cm^2. Arrays of PIN diodes, dosimeters and nuclear-activation detectors measure the angular distributions of photons with energies greater than 0.5 MeV. The PIN diodes, with 1 cm^2 by 500-µm sensitive volume, are housed in lead pigs with 2.5-cm thick walls. Measured emission intensities have been as high as 5×10^{13} γ MeV/steradian. The angular distributions are highly directed in forward directions, with significant variations on a shot-to-shot basis. Backward radiated intensities tend to be more than a decade lower than in forward directions.

I. Introduction

An ongoing sequence of experiments is studying the interaction of short intense laser pulses with planar solid targets. The laser pulses, with wavelength of 1.06 μm, source energies typically from a few hundred to 700 joules, and approximate durations of either 5 psec or 0.5 psec. An f 3.0 parabolic mirror focuses the 50-cm laser beam to spots with sizes that vary from ten to hundreds of μm. Targets consisting of multiple layers of plastics and/or metals with thicknesses from a few to hundreds of μm intercept the focused laser beam, either with normal incidence, or at a 45° angle.

A broad variety of optical, x-ray, M-eV photon, nuclear, and energetic particle diagnostics characterize the laser-target interaction for each experimental shot. One consistent feature of the interaction is the emission of a prompt bright flash of photons with energies capable of penetrating more than 5 cm of solid lead. These flashes generally saturate photomultiplier/ scintillation detectors, but silicon PIN diodes respond within their linear ranges. Data recorded with PIN diodes show that the "hard" photon flash has a variable collimated angular distribution, with peak intensity often near the direction of the incident laser. The emission intensity is not always consistent on a shot-to-shot basis, but it generally increases with laser energy, with decreasing pulse duration, and with increasing target atomic number.

II. Description

The PIN detectors consists of PIN diodes placed inside lead "pigs" with 1-" wall thickness, which themselves are arranged around the outside of the petawatt target chamber in order to sample the photon angular distribution. Figure 1 shows a typical arrangement of about 15 PIN diodes for sampling the hard photon angular distribution. The PIN diodes have a sensitive volume of 1 cm^2 area by either 250- or 500-μm depletion thickness. The detectors use separate signal and high-voltage lines, require a minimum of 50 volts for full depletion, and are linear to more than 10 amps with the +700-volt bias voltage. Tektronix 684B transient digitizers record pulses from the individual detectors, which then are integrated to obtain the recorded photon dose from each detector.

Absolute calibration of the PIN sensitivities is a complex problem because electron showers from the pig tend to increase the net PIN sensitivity beyond the values that would be expected from simple response to an incident photon flux. The absolute sensitivity of the detector assembly (including the pig) was measured directly, using a 13-kiloCurie Co^{60} γ-ray source. The calibration geometry simulated the geometry of the petawatt experiments. The measured sensitivities, 4.5×10^{-17} (or 2.28×10^{-17}) Coul/γ-MeV for 500-μm (or 250-μm) detectors produce results that agree well with standard thermoluminescent detectors (TLDs).

III. Results

Figure 2 shows a typical recorded signal that was generated by a PIN diode. There is a noticeable noise component, but integration of total charge in the pulse provides good precision for measuring the radiation dose associated with the photon flash. The recorded pulse width of about ten ns cannot reveal the temporal structure of the flash, but later-time backgrounds and signals can be excluded from the data. This method can record doses as high as several rads, or as low as one mrad.

Figure 3 shows a typical set of data from a recent series of petawatt shots with 0.5 psec laser pulse length. Doses recorded on the PIN diodes vary from a few mrad to several rads. The highest doses are in near-forward directions, and lowest doses in backward directions. Shot-to-shot variations in relative amplitudes between the detectors indicate changes in the shape of the photon angular distribution. Variation in absolute amplitude show also that the photon dose does not always scale with laser energy.

Figure 4 is a different presentation of results from a similar previous series of petawatt shots with 0.5 psec pulse durations. This plot emphasizes the much higher intensities that are observed in forward directions.

IV. Discussion

The data above demonstrate several basic features of MeV photons that are generated when extremely bright laser pulses strike planar solid targets: The flashes are bright, in that the hard photon flux can induce radiation exposures in excess of one rad at a distance of one meter from the target. The radiation intensity increases with increasing laser intensity, both spatially and temporally. The radiation intensity also increases with target Z. These general behaviors are quite consistent, but the experiments also can show dramatic variations in radiation intensities and distributions on a shot-to-shot basis.

The variations in radiation output are not completely understood. Variations in the angular distribution likely are due, at least partially, to small changes in the spatial and temporal form of the laser pulse. The mechanisms behind radiation production appear to be highly nonlinear, because small changes in the laser pulse sometimes lead to dramatic changes in the radiation angular distribution. This is particularly true for the observed direction of the radiation peaks intensity. Some of this behavior is evident in Fig. 3.

V. Conclusion

Solid-state silicon PIN diodes have measured the production of photons with energies in the M-eV range from experiments with short-pulse lasers and planar solid targets. The measured radiation doses can exceed 1 rad at a one meter from the target. The angular distributions are collimated in forward direction, but also can show dramatic variations in direction on a shot-to-shot basis. This work was performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under Contract number W-7405-ENG-48.

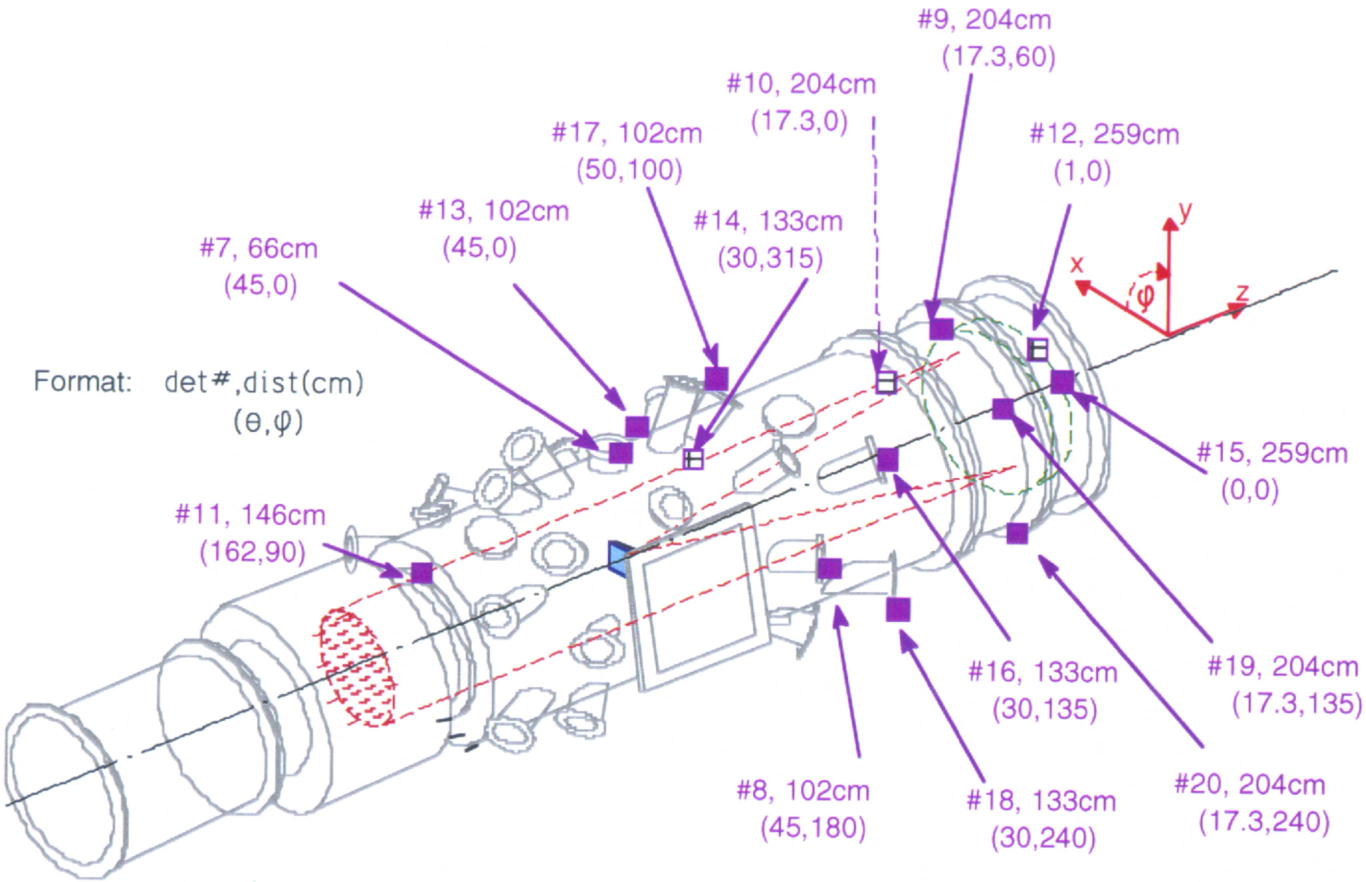

Figure 1: Petawatt/ PIN-diode layout.

Here, fourteen PIN diodes are arranged to sample the angular distribution of photons having energies in the MeV regime. The laser pulse (red) enters the chamber from the left, is reflected by an f-3.8 parabolic mirror (green) toward a plasma mirror (blue), where it is reflected again into the forward direction onto the solid target.

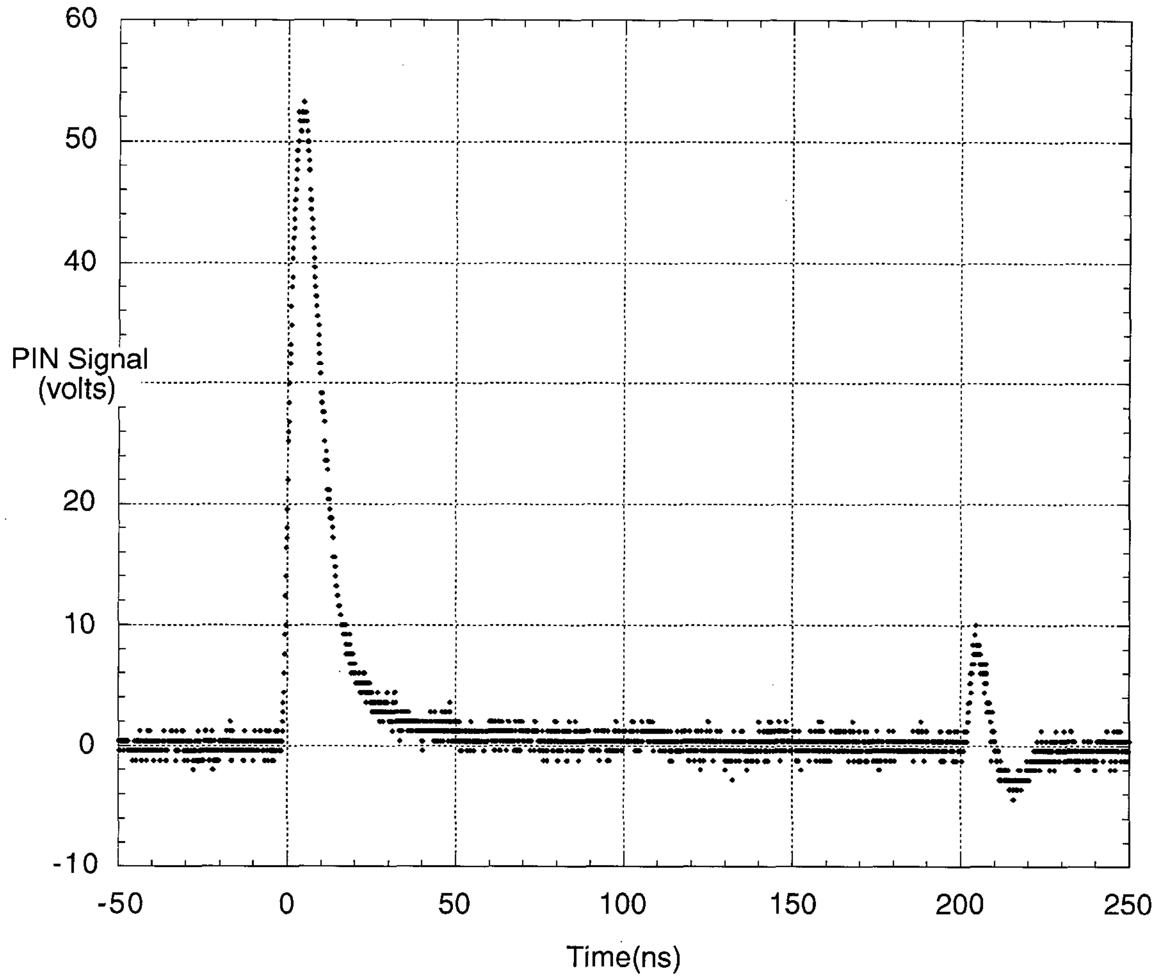

Figure 2
This plot shows a typical PIN-diode signal. The pulse shape varies slightly with signal amplitude, but the integrated charge varies linearly with photon dose. The small pulse at 200 ns is associate with a reflection from the 100-ns long high-voltage cable.

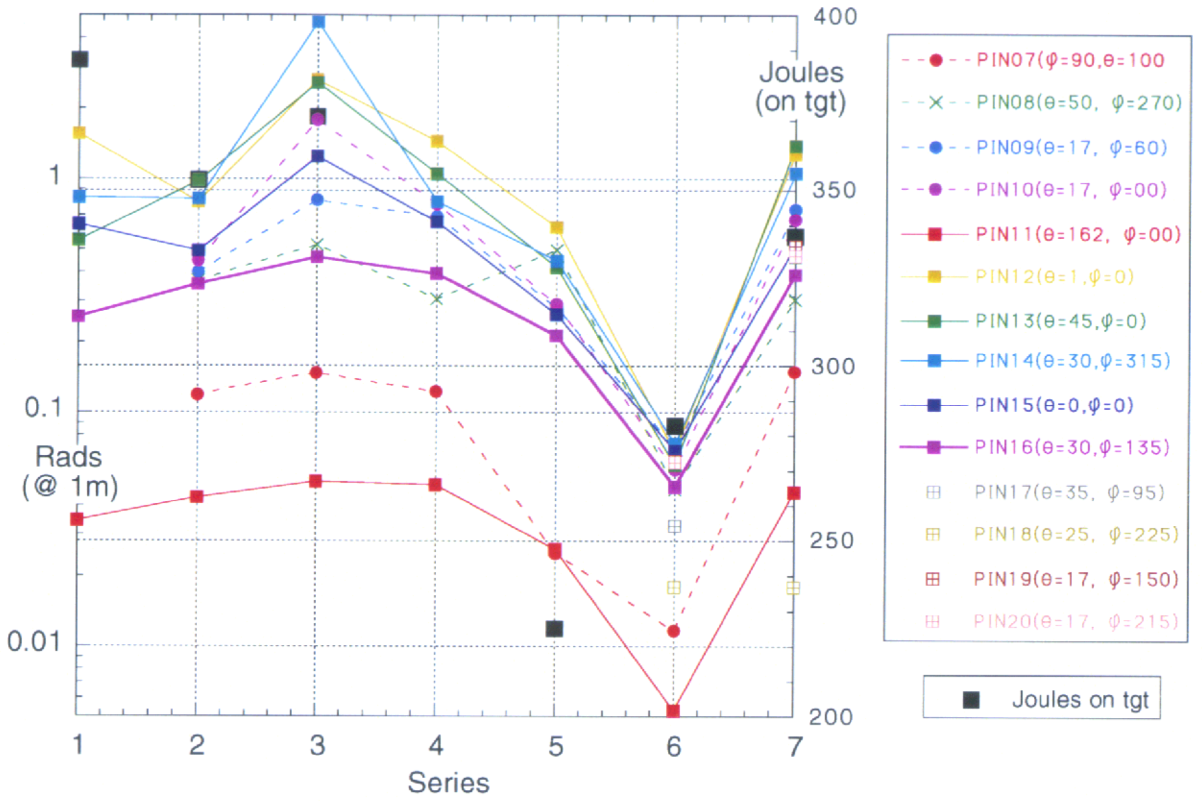

Figure 3

The integrated doses obtained from fourteen PIN diodes are shown here for a series of seven shots in June, 1998. Doses are highest (up to several rads) in the forward directions, with doses in backward directions being as much as two decades smaller. The variation in relative doses indicates shot-to-shot changes in the shape of the angular distribution of the radiation.

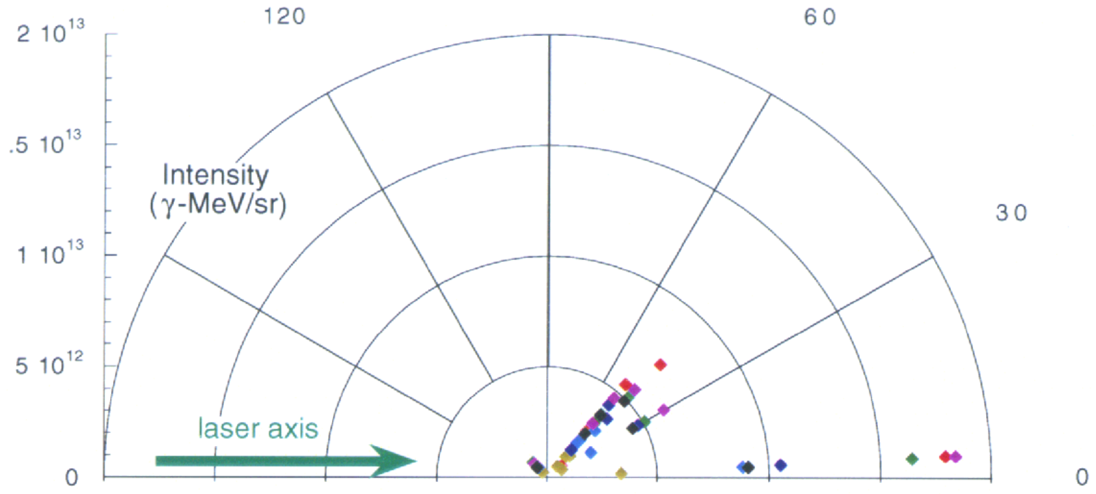

Figure 4
This polar plot shows the dramatically higher intensities in the forward directions. Here, results are shown for a different but similar series of shots (compared to Fig. 3). The colors of the diamonds correspond to data from a specific shot. This two-dimensional format suppresses azimuthal variations, so only the polar angle of the radiation is indicated.