SLAC RPG Measurement of Ionizing Radiation from CO_2 laser interactions at ATF

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ATF User Meeting 3/1/2023

U.S. DEPARTMENT OF ENERGY Office of Science

SLAC NATIONAL ACCELERATOR LABORATORY

Motivation

Increasing intensity of lasers will continue to push their operation into regimes where ionizing radiation can be generated

Current state of the art models rely on coupling Particle in Cell codes with Monte Carlo Radiation Transport Codes

In order to be sure models are producing reasonable estimate of ionizing radiation from the laser plasma interaction experimental benchmarks with a variety of laser parameters are needed.

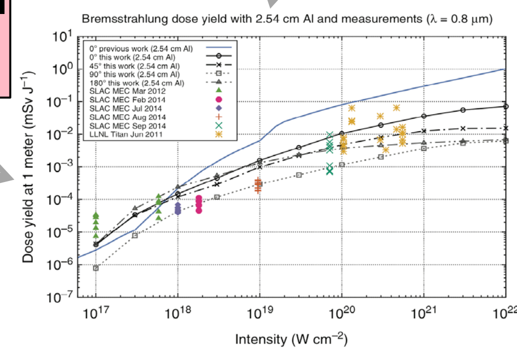
Laser-Induced Ionizing Radiation from Solid Targets

Particle-in-Cell Code (EPOCH)

Calculated **source term** for solid target: spectrum (Maxwellian) and direction of electrons for given irradiance

Calculate **dose yield (mSv/J at 1 m)** outside 1 inch thick Al target chamber

Measurements of dose yields outside MEC & Titan target chambers



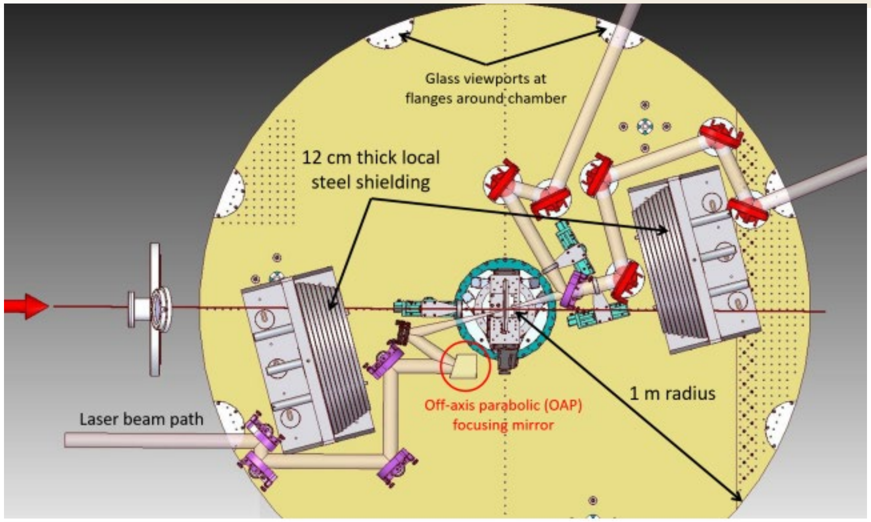
Radiation Particle Transport Code (FLUKA)

Calculate **dose at ATF** parameters (irradiance, energy/shot, number of shots, shielding geometry)

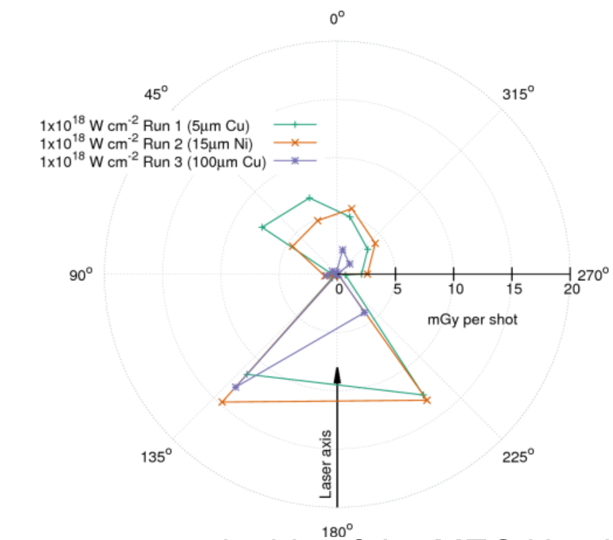
Additional sources for liquid targets and thin solid targets:

- High energy protons/ions (hazard of secondary neutrons)

Previous Work and Publications: Laser-Induced Ionizing Radiation from Solid Targets



Experimental Configuration of MEC Hutch at SLAC

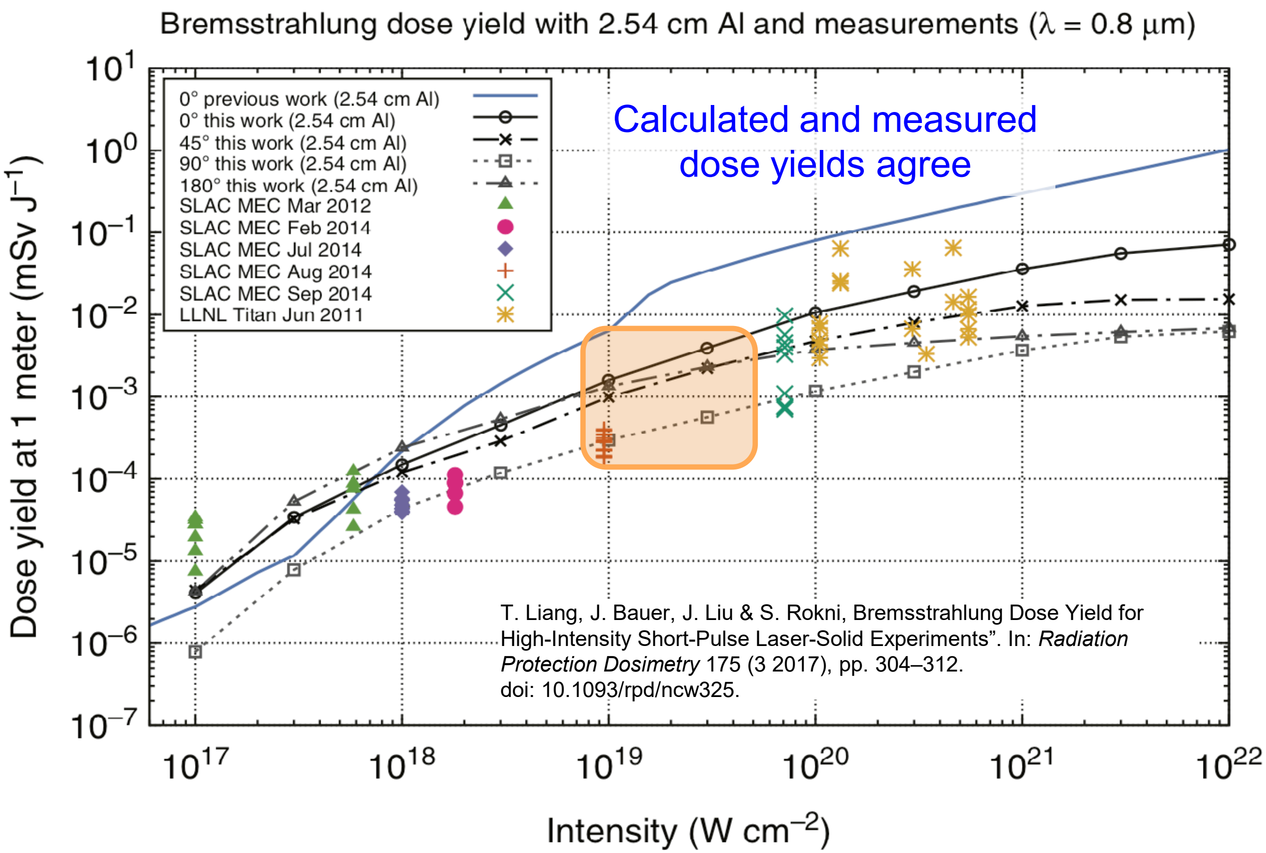


Dose Measurements inside of the MEC Hutch at SLAC

Previous Publications and SLAC Radiation Physics Notes:

- T. Liang, PhD dissertation, Georgia Institute of Technology & SLAC, 2017
- Liang, T., Bauer, J., Blaha, J., Cimeno, M., Ferrari, A., Liu, J., Rokni, S., and Woods, M., "Ionizing Radiation Measurements from Interaction of MEC Laser (0.7 J, 1019 W/cm2) with Cu and Ni Targets," SLAC Radiation Physics Note, no. RP–14–23, pp. 1–22, 2014.
- Liang, T., Bauer, J., Cimeno, M., Ferrari, A., Galtier, E., Granados, E., Lee, H. J., Liu, J., Nagler, B., Prinz, A., Rokni, S., Tran, H., and Woods, M., "Radiation Dose Measurements for High-Intensity Laser Interactions with Solid Targets at SLAC," Radiation Protection Dosimetry, vol. 172, no. 4, pp. 346–355, 2016.
- Liang, T., Bauer, J., Cimeno, M., Ferrari, A., Galtier, E., Granados, E., Liu, J., Nagler, B., Prinz, A., Rokni, S., Tran, H., and Woods, M., "Measurements of High-Intensity Laser Induced Ionizing Radiation at SLAC," SLAC Publication, no. SLAC-PUB-15973, pp. 1–18, 2014.
- Liang, T., Bauer, J., Liu, J., and Rokni, S., "Bremsstrahlung Dose Yield for High-Intensity Short-Pulse Laser-Solid Experiments," Radiation Protection Dosimetry, 2016.
- Liang, T., Bauer, J., Liu, J., and Rokni, S., "Development of a Photon Dose Yield Model for Laser-Solid Interaction by Coupling EPOCH and FLUKA," SLAC Radiation Physics Note, no. RP–16–14, pp. 1–28, 2016.

Applying Previous Work to ATF



Good agreement between model and experimental measurements for 800 nm and 1053 nm lasers

ATF Operational Range :

$I \rightarrow 5.4 * 10^{16}$ @ $10600\ nm \rightarrow$ *need to correct for wavelength*

$$I_{corrected} * 800^2 = 5.4 * 10^{16} * 10600^2$$

$$I_{corrected} = \frac{5.4 * 10^{15} * 10600^2}{800^2} = 9.5 * 10^{18}$$

Upgrade: 2 ps pulse and 20 J

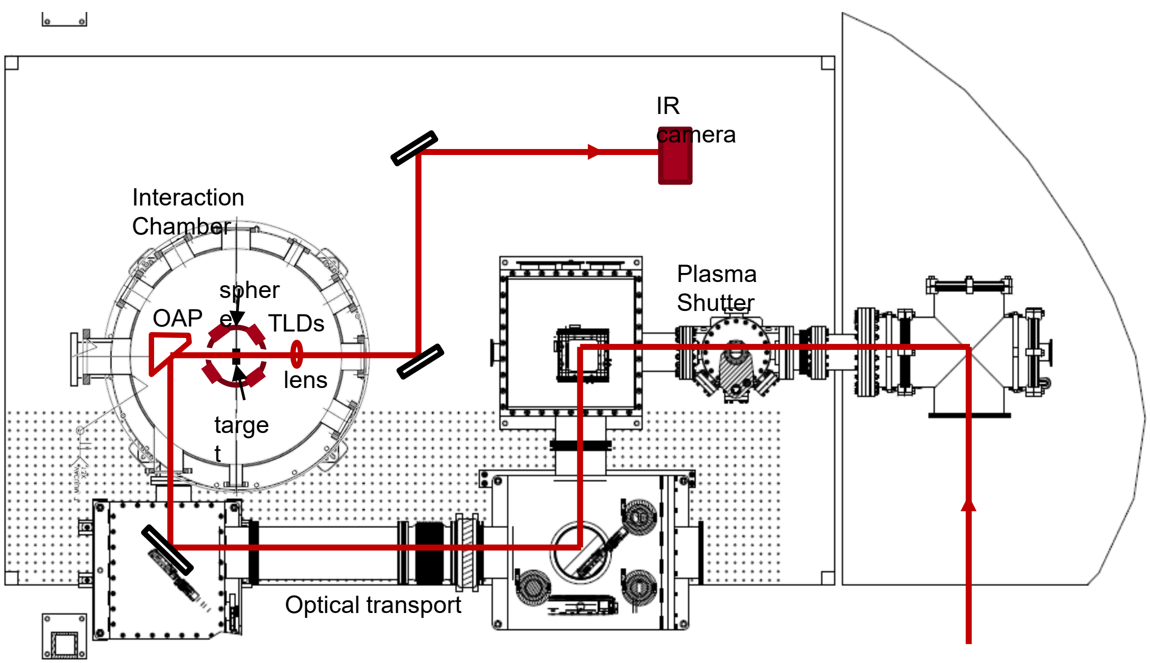
CO2 Laser @ $2.5 * 10^{17} \rightarrow 4.4 * 10^{19}$

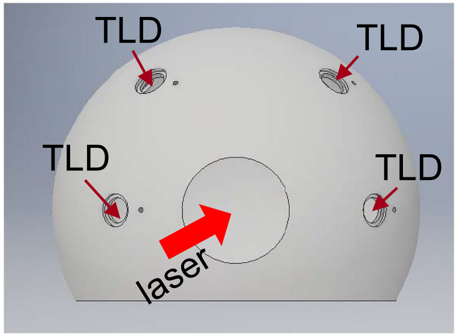
Slide adapted from M. Palmer and ATF team

Previous Work: Motivation

Goals:

1. Directly measure the x-ray source field within the vacuum chamber
2. Apply a thin Al filter (thickness of 3.35 mm) to distinguish low energy (< few 10s of keV) x-ray dose from high energy dose
3. Obtain measurements ***near likely ultimate parameters*** for B820 operation to aid future analysis of upgrades [extrapolate to lower fluences for radiation safety analysis]





Test sphere 6” diam.; windows are for placing TLDs around a target

Slide adapted from M. Palmer and ATF team

Previous Work: Experimental Study Parameters

Designed to significantly exceed the present and potential upgrades to operational configuration of the plasma shutter!!

Relevant laser parameters for test dose rate estimate:

Laser pulse length	2.3 ps
Laser pulse energy	5 J
Laser pulse rep rate	0.03 Hz
Energy fluence @ 5 J	6.25E5 J/cm^2
Laser intensity @5J and 2.3 ps	2.7E17 W/cm^2
Plasma kT_H (Ref 1)	976 keV
Hard X-ray energy / laser energy (Ref 1)	0.011 (range is 0.00737 to 0.0165)

Ref 1: Physical Review A Volume 32, Number 6 December 1985, Superhot-X-Ray and -Electron Transport in High-Intensity CO2-Laser-Plasma Interactions, G. D. Enright and N. H. Burnett.

Slide adapted from M. Palmer and ATF team

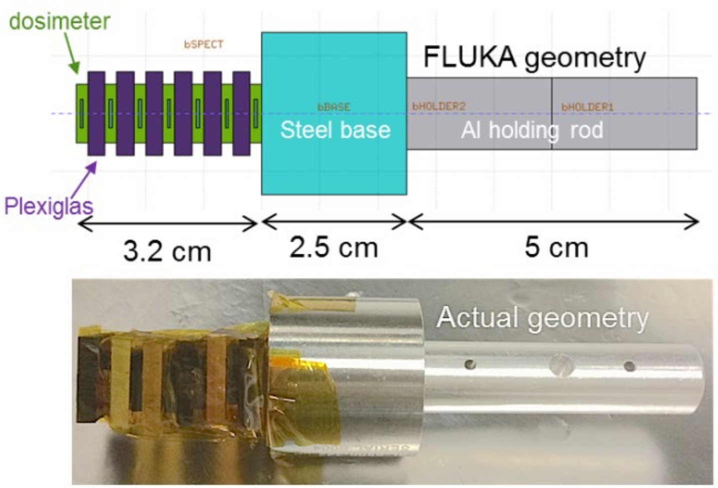
Previous Work: Results

Nanodot Serial #	Rad in an hour (108 laser pulses in an hour)	Location
DB08650715G	1.042	1a
DB086529564	1.241	2a
DB08653362M	2.978	3a
DB08652850I	16.03	4a
DB08630542R	492.2	1
DB08630517K	860.1	2
DB08652923D	927.6	3
DB08650691I	2,768	4

Proposed Experiments

Conduct passive and active spectral and dose rate measurements of the radiation that is produced from a solid target interaction at several intensities and angles

- This will enable a comparison of the model produced using 800 nm to a very different wavelength (10600) to show the wide range of applicability for the model and $I\lambda^2$ scaling for use in radiation protection assessments

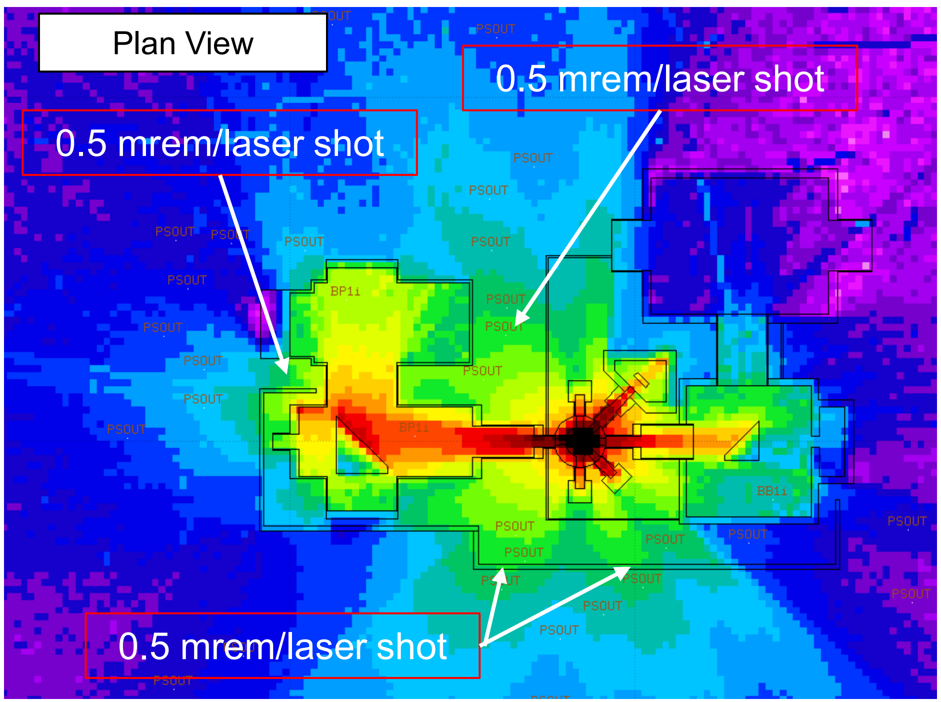


Stacked dosimeters used for passive spectral measurements

Ambient dose Ion chamber for active dose measurements

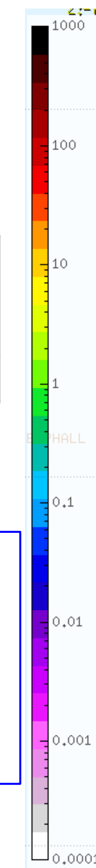
Application at the ATF

This work would support analysis of fault conditions in the ATF plasma shutter



Intensity on Pinhole surface (Normal Operation) [W/cm^2] @ 800 nm	T_h [keV]	Laser to electron conversion efficiency	Forward to backward ratio
2.52E+18	305	0.45	0.82

The maximum dose rate at the exclusion barrier would result in 200 shots before the 100 mrem limit is reached



mrem/laser shot

Conclusion

Coupled PIC and Monte Carlo Radiation Transport codes are useful tools in developing mitigations for ionizing radiations produced by high intensity laser interactions

In order to reliably predict the dose to personnel using state of art models, benchmarking of the angular distribution, radiation spectra, and dose rate are needed over a wide range of laser conditions