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Title: High Intensity Gamma Ray Source Scintillation Attenuation Spectrometer and Filter Stack Monoenergetic Calibration

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High Intensity Gamma Ray Source Scintillation Attenuation Spectrometer and Filter Stack Monoenergetic Calibration

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On behalf of the Laser-Based X-Ray Radiography Team

The Laser-Based X-ray Radiographic Imaging team at Los Alamos National Lab is looking for a monoenergetic MeV X-ray source to both verify our Monte Carlo N-particle simulations of detector performance and calibrate the instruments for future measurements. Funded by the Laboratory Directed Research and Development (LDRD) program, our overall goal is to improve the radiographic quality and reliability of laser-based X-ray sources for deployment at both dynamic and static radiography facilities. Laser-based X-ray sources have demonstrated smaller spot sizes to current electron accelerator based sources. The smaller laser spot size leads to significantly improved resolution (Figure 1).

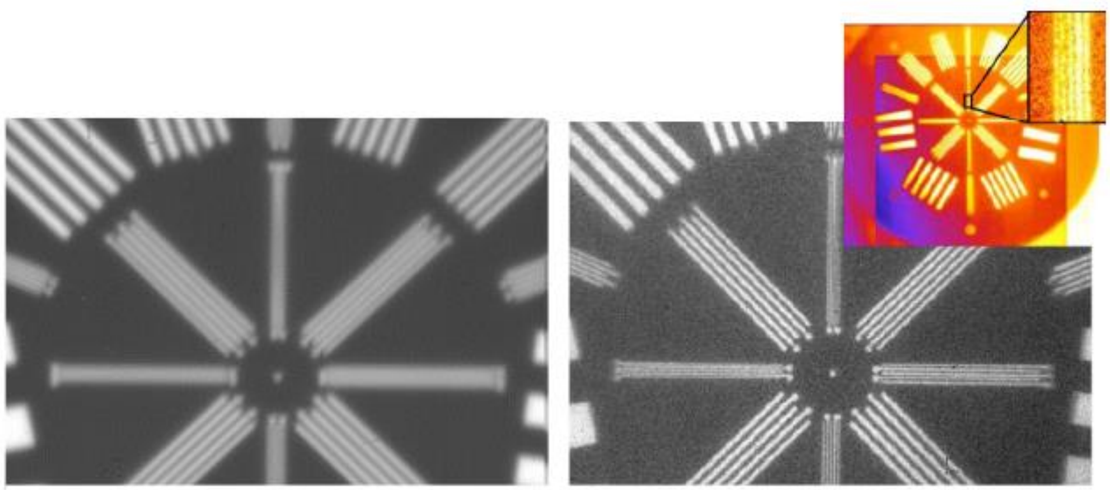

Figure 1: Radiography of test object from the Microtron electron accelerator (left) and Trident laser base X-ray source (right). The improved resolution possible with a laser baser source due to the much smaller spot size (< 100 um) is clear. Image from Cort Gautier, E-6, LANL.

A challenge in our current experiments is accurately measuring the X-ray spectra of the ultrafast pulses (<1 ps). MeV photon fluxes from laser-driven sources are in an intermediate regime that makes the spectra difficult to measure. The fluxes are too low to readily use Compton, and the fluxes are too high for single photon counting. The limited space in the laser radiography bays also complicate the use of large and heavy detectors; the LANL X-ray Compton detector weighs near 2 tons. Finally, we would like a detector that responds on the same timescales as the short laser pulses and can support rep rated operation.

In our first laser campaign we deployed a filter stack spectrometer with limited success. In our most recent campaign we deployed an upgraded filter stack spectrometer, a newly purchased scintillation attenuation spectrometer and Cherenkov detector borrowed from Sandia. We would like to explore verification and calibration measurements for the filter stack and the scintillation instruments at HIGS.

The filter stack spectrometer (FSS) is a bremsstrahlung spectrometer that "uses Z and differential lead (Pb) filtering to determine the x-ray spectrum up to a MeV in energy." (Link) The 15-20 filters are sandwiched with image plates in a W housing for shielding (Figure 2). Image plates are flexible sheets of plastic doped with lanthanides which capture an X-ray image and can be read by a specialized scanner. FSS can measure a single high intensity MeV x-ray pulse or average a large number of pulses on the image plates. This detector type depends strongly on the image plate brand and scanning system as no two systems are equivalent, even those advertising the "same" material. Each combination of image plate and scanner needs to be calibrated for quantitative measurements. Using the FSS is a labor-intensive process. After each shot the image plates are removed, scanned and erased, and the spectrometer is rebuilt for the next shot.

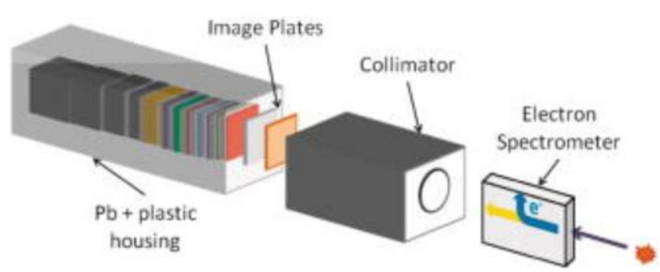

Figure 2: A typical filter stack spectrometer setup. Our housing is tungsten with a 6 mm hole in the collimator and layers of plastic, aluminum and lead filters. The magnetic dipole electron spectrometer in front of the FSS removes charge particles so they do not contribute to the signal. Image from Chen et al; see link in paragraph above.

The scintillation attenuation spectrometer (SAS) was purchased from Edison Liang at Rice University who developed the concept. (Link) "The basic idea is to image the two-dimensional (2D) scintillation light pattern emitted by a finely pixelated scintillator matrix when it is irradiated sideways by a narrowly collimated beam of gamma-rays." The SAS is like a 48 filter stack made from a single material that can measure short pulse X-rays at high repetition rates (Figure 3) The 2D images of the scintillator showing the X-ray attenuation pattern are distinct for different energies and can be used to reconstruct the incident X-ray spectrum. (Figure 4)

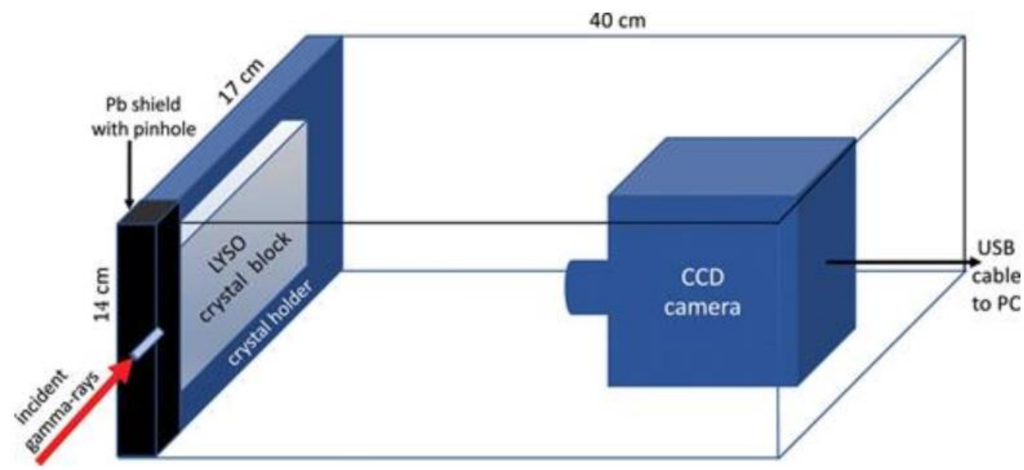

Figure 3: Sketch of the SAS layout. The light tight housing is transparent in this drawing to show the internals. From Liang et al; see link in paragraph above.

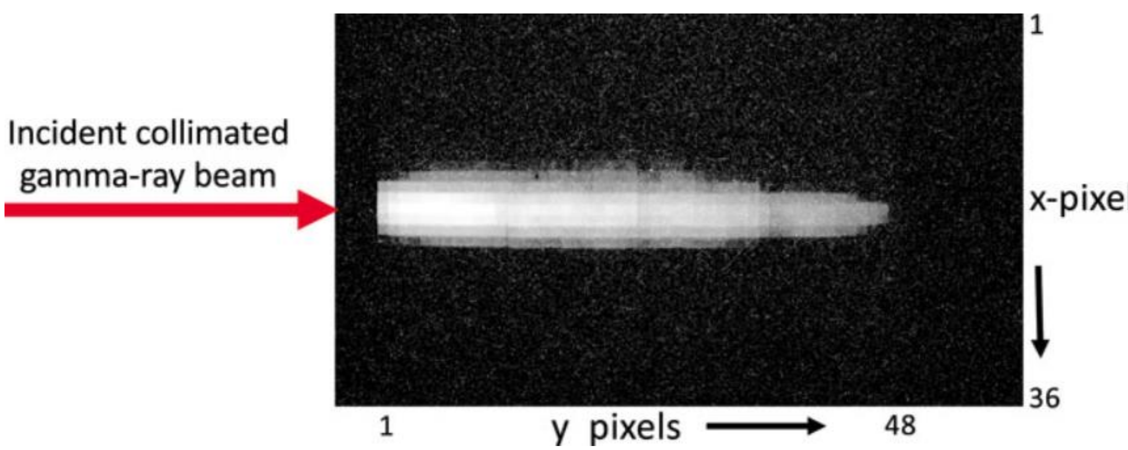

Figure 4: Raw image of 2016 Texas Petawatt experiments by Edison Liang. Gamma-rays entered the crystal block from a 6 mm-diameter pinhole at the center of the left edge. This image shows over 350 visible bright pixels, with all pixels along the central axis luminous except the last pixel. From Liang et al; see link in paragraph above.

All of these detectors require a calculation algorithm to extract the spectra from the measured data. First a response matrix of the detector to X-ray irradiation at different X-ray energies is developed using MCNP (FSS) or Geant4 (SAS). Then the inverse response matrix is calculated and used to extract the spectra from the detector images. This is a perturbative minimization iterative process with ~100 steps to find the estimated spectra. The spectral estimation has an error of about 10%. The accuracy of this algorithm has not been verified for the FSS detector and only checked with natural gamma ray sources for the SAS detector. With calibration at the HIGS we hope to get down to an error of ~1%.

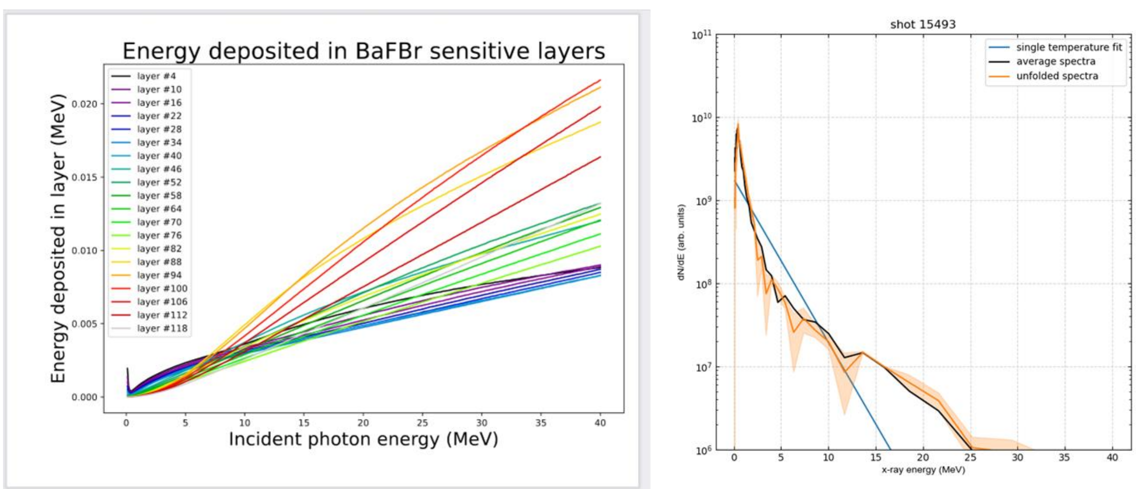

Figure 5: Response matrix of the image plates in the filter stack as modeled in MCNP. (right) Sample laser X-ray unfolded spectra, in orange with error shading. (left) Most of the error is in the MeV range where the attenuation of the filter stack is similar for all materials. Improvements in this region with calibration at HIGS would be significant.

The objective of the HIGS beam time is to measure defined monoenergetic X-ray sources to calibrate our detectors and verify the spectra extraction algorithms. The most important parameters for the HIGS beam is a known delivered X-ray spectrum – the peak, FWHM, shape, and energy content. We also want to know the X-ray intensity and have the ability to adjust the exposure time, gain and other parameters of the detectors to collect good images. We would like to take as many shots at different energies as possible during our beam time. My vision for the experimental campaign is listed below:

1. At a few HIGS beam energies use the HPGe detector to measure the complete spectra.
    a. At the other energies use the laser and electron beam parameters to calculate the inverse Compton X-ray spectra.
2. Setup HIGS beam at 2 MeV
3. Place FSS detector in beam line and irradiate for x time.
    a. Scan image plates while other detectors are imaged.
4. Place SAS detector in beam line and irradiate for x time.
    a. Monitor the camera images from the control room.
5. Switch HIGS beam to a new energy. Repeat detector measurements.

The number of energies we can measure would depend on the speed the HIGS beam can be adjusted to a new energy. The exposure time for the SAS and can be monitored and adjusted from the control room. We may need a few runs to dial in the correct exposure for the FSS. I anticipate needing at most 1 hour for the detector measurement portion (steps 2-5) at each energy. That time includes setup, switching out the detectors, and collecting the data at each energy.

We would expect the HIGS staff to assist with setup in the experimental chamber, run the HPGe detectors, run the accelerator and FEL laser, and provide instrument parameters at each energy including:

1. Accelerator Parameters for Compton Calculation
    At the interaction point.
    a. e Beam Spectra
    b. e Beam Current
    c. e Beam Spatial
2. FEL Parameters for Compton Calculation
    At the interaction point.
    a. Laser Spectra
    b. Laser Energy
    c. Laser Spatial
3. HIGS Compton Calculation
4. HIGS X-ray Measured Spectra
    a. Measured at key energies from HPGe
5. X-ray Intensity (gamma/sec × cm^2 or W/cm^2)

The LANL team would be responsible for the detectors and the data collection system for each detector.

1. Filter Stack Spectrometer
    a. Detector
        i. W Case
        ii. Filters
        iii. Image Plates
    b. Image Plate Scanner
    c. Computer
2. Scintillation Attenuation Spectrometer
    a. Detector
        i. LYSO
        ii. Camera
        iii. Lens
        iv. W shielding
    b. Computer
    c. GigE power over ethernet
    d. BNC trigger

Most of this equipment is already prepared in Pelican cases and has been shipped around the country to our other laser beam experiments.

These measurements will be extremely valuable to the MeV X-ray work at LANL. We do not anticipate writing a standalone work on the HIGS experiments; however, it will provide an important benchmark and will be acknowledged in several forthcoming scientific papers. It is possible that if the FSS calibration is successful at reducing the error of the unfolding to ~1% that the FSS instrument and our unfolding algorithm will receive its own paper in Review of Scientific Instruments.