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Multi-GHz Pulse-Train X-Band Capability for Laser Compton x-ray and gamma-ray Sources

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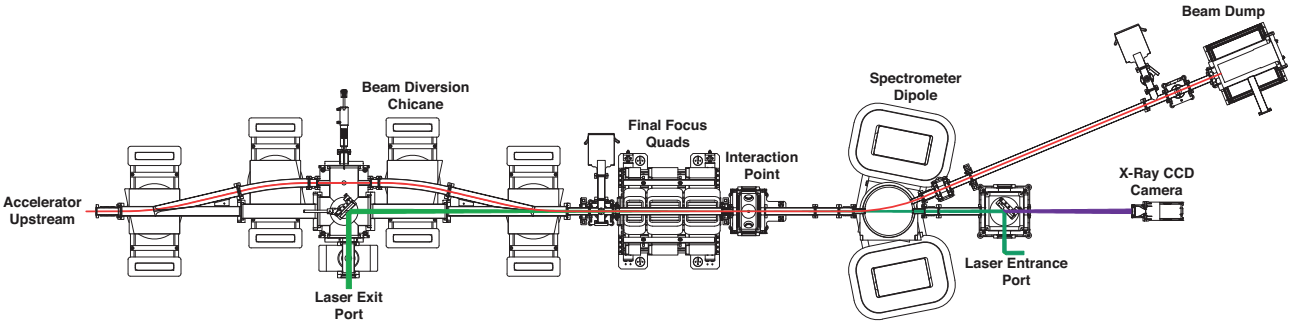

Figure 1: Cross section interaction region of the laser-Compton system. The accelerator sits to the left of the figure. The electron (red), laser (green) and x-ray (purple) paths are shown.

ACCELERATOR

The accelerator is built around a state-of-the-art X-band RF photoinjector [4]. RF power is provided by a 50 MW 11.424 GHz SLAC built XL4 klystron powered by a solid-state Scandinova modulator. The RF power provided is of very high phase and power stability, providing excellent electron beam consistency. A 5.59 cell RF gun incorporates LCLS S-band gun improvements, producing 7 MeV submicron emittance bunches in excess of 100 pC. The electron beam energy is boosted by a T53 traveling wave accelerator section to a maximum of 31 MeV. A chicane is used to shield x-ray experiments from dark current and allow for an interaction laser exit path. The electron beam energy is measured with a dipole spectrometer and captured in a shielded dump. Other diagnostics include ICTs, YAG screens, and OTR measurements. A more detailed status of the X-band test station can be found in [5].

Initial optimization is made with all but the fixed-delay arm of the hyper-Michelson pulse stacker blocked. After optimization of the beam performance for a single electron bunch, the beam blocks in the hyper-Michelson are adjusted to allow a different single bunch through. A Schottky scan is performed with this pulse. The results are used to dial in the delay of the hyper-Michelson arm to deliver the laser pulse at the optimal 20° operational phase, but with a single RF-period delay. This process is repeated for the second delay arm, inserting a 2-period delay and yielding a 4-pulse bunch train with each bunch separated by a single 87.5 ps RF cycle. This spacing is verified by a streak camera measurement of optical transition radiation (OTR) light from the beam (Fig. 2). The energy of each electron bunch is verified, and when tuned correctly the bunch-to-bunch spread is comparable to the single bunch energy spread.

The emittance of multiple simultaneous bunches is currently being measured. Preliminary results show no significant degradation of performance between single-bunch and multiple-bunch operation. Beam dynamics modeling is underway to distinguish the effect of bunch-to-bunch emittance growth and statistical variation in the images used for the quad scan parameter fitting. Ultimately, streaked OTR-based quadrupole scans will be able to simultaneously measure the emittance of each bunch, and confirm operation of Laser-Compton sources in multibunch modes.

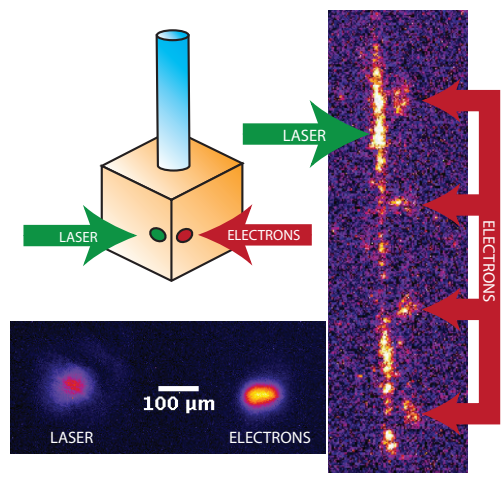

Figure 2: Left top: Alignment configuration. Left bottom: laser and electron OTR at the interaction point. Right: Streak camera image with a portion of the interaction laser alongside OTR from four electron bunches with 87.5 ps spacing.

INTERACTION

Fig. 1 shows the design of the interaction region. As mentioned above, the electron beam passes through a chicane which allows for a tungsten plug to be inserted on axis to reduce dark current bremsstrahlung noise on the x-ray detector. The beam is then focused with a quadrupole triplet and, after interaction, passes through an energy spectrometer which separates the electron beam from the x-rays.

Meanwhile, the 9 mm diameter interaction laser beam is enlarged to 18 mm before being focused with a 1.5 m lens. The beam passes through the vacuum window, and is directed by a final optic to the interaction point. Because the x-ray beam will have to pass through this mirror, a hole has been counterbored in the back of the optic to reduce the fused silica thickness to 2 mm where the x-ray beam passes through. After the interaction, the beam is collected by a mirror in the middle of the chicane and directed into a beam dump.

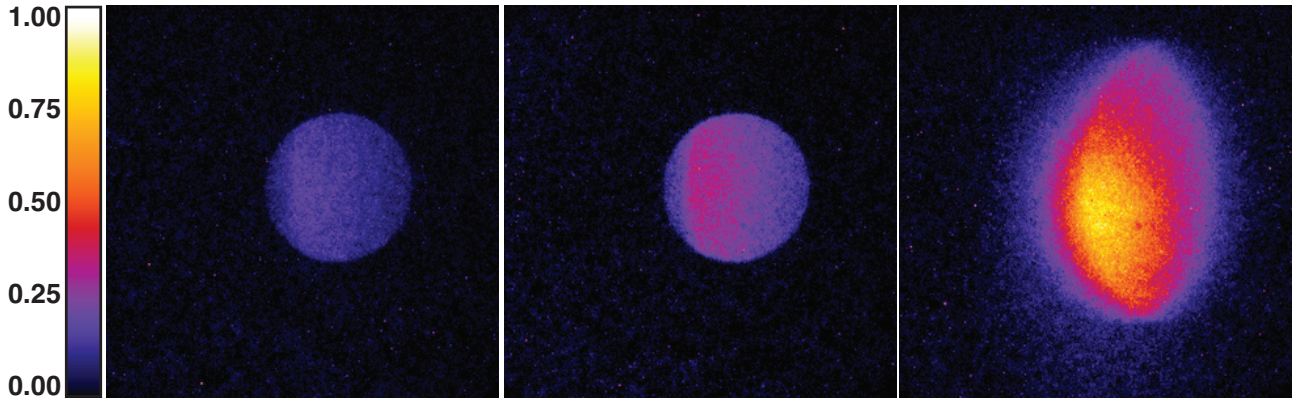

Figure 3: X-ray images with (left) one, (center) two, and (right) four electron bunches interacting with a single laser pulse. The one and two bunch images are clipped by an alignment iris, which was removed for the four-bunch experiment.

The electron beam and laser were aligned using a Ni cube aligned at 45 degrees to the beamline, which directs the attenuated laser beam and optical transition radiation from the electron beam to either a standard camera or a streak camera. Fig. 2 shows a streaked image verfying the spacing of four adjacent electron bunches, spaced 87.5 ps apart, alongside a portion of the interaction laser pulse.

PRELIMINARY X-RAY RESULTS

For the x-ray demonstration, we used a Continuum Powerlite DLS 8010 laser, providing up to 750 mJ of 532 nm light with a 6 ns FWHM pulse length. This long length means that most of the light won't see the 2 ps long electron beam, so the flux will be 100x smaller than it could be with a shorter laser. For purposes of studying the electron beam performance, however, it is sufficient. Fig. 4 shows the expected flux for this interaction as a function of laser focal spot size, which was chosen to optimize x-ray generation

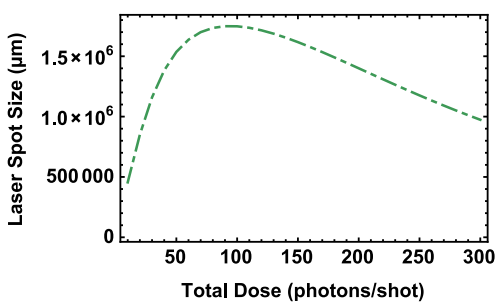

Figure 4: Predicted total flux as a function of laser focal spot size for a 750 mJ, 6 ns, 532 nm laser interacting with a single 100 pC, 0.4 mm mrad, 30 MeV electron bunch.

The generated x-rays were detected by a 145 μm CsI(Tl) scintillator layer grown on a fiber plate, which is coupled to a 3:1 fiber reducing bundle. This bundle is in turn coupled to a gated, intensified Andor iStar ICCD camera. 3 shows the measured x-ray profile for one, two and four bunches on the same color scale. The aperture shown is a 12 mm diameter located at a distance of 1.5 m from the interaction point, corresponding to an 8 mrad beam cone. These images show, as expected, a roughly linear increase in x-ray flux with the total beam current. The imaging system response has not yet been calibrated to allow conversion of measured counts into energy deposited.

CONCLUSION

LLNL's laser-Compton source is operational and now offers a valuable test bed to optimize all areas of source development. Initial tests show promise for the multi-GHz architecture's ability to provide a higher-current beam, significantly improving laser Compton x-ray source performance. The next significant step is to integrate the multi-GHz laser system with the x-band accelerator and study the beam performance with 100 bunches and determine at what number of pulses, and what charge per pulse, the beam wakefield effects become to disruptive and explore any necessary mitigation.

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