FY22 LaserNetUS Program

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UR/LLE is part of the LaserNetUS Collaborative Network established in 2018 and funded by the Department of Energy Fusion Energy Sciences within the Office of Science. The mission of LaserNetUS is to reestablish U.S. scientific competitiveness in high-energy-density physics and high-field optical science by advancing the frontiers of laser-science research, providing students and scientists with broad access to unique facilities and enabling technologies, and fostering collaboration among researchers and networks from around the world. During FY22, LaserNetUS facility nodes consisted of ten institutions including Colorado State University, Lawrence Berkeley National Laboratory, Lawrence Livermore National Laboratory (LLNL), SLAC, The Ohio State University, the University of Central Florida, the University of Nebraska-Lincoln, Institut National de la Recherche Scientifique, the University of Rochester, and the University of Texas at Austin. Through a coordinated annual call for proposals and an independent proposal review panel process, the LaserNetUS network makes available a variety of ultrafast, high-peak-power and high-energy, petawatt-class lasers including LLE's four-beam, high-energy and high-intensity OMEGA EP laser to users who do not have regular access to ultrahigh-intensity lasers.

UR/LLE provides an average of four shot days each year on OMEGA EP to LaserNetUS users. Since 2019, 18 projects have been awarded a total of 20 shot days on OMEGA EP, including 13 projects from the first three solicitations for shots in Cycle-1 (2019–2020), Cycle-2 (2020–2021), and Cycle-3 (2021–2022), and five new projects from the fourth solicitation completed during FY22 for experiments in Cycle-4 (2022–2023). During FY22, a total of 34 target shots were successfully conducted over four shot days for three LaserNetUS projects led by scientists from Princeton University, the University of California, San Diego (UCSD), and Lawrence Livermore National Laboratory (see Table I below). These three experiments involved three graduate students and four postdoctoral researchers. FY22 LaserNetUS user experiments are summarized below.

Table I: During FY22, three LaserNetUS Cycle-3 projects (blue-shaded cells) completed 34 target shots over four shot days and five new LaserNetUS projects selected from the Cycle-4 solicitation were approved with a total of five shot days for experiments on OMEGA EP in FY23.

Principal Investigator	Institution	Title	LaserNetUS beam-time cycle
M. R. Edwards	LLNL	Reaching an Electron–Positron Plasma with OMEGA EP	3
G. Righi	UCSD (now at LLNL)	Understanding Temperature Dependence of Iron Strength at High Pressure with Ramped Compression on OMEGA EP	3
S. Zhang	Princeton University	Study of Particle Acceleration in Magnetic Reconnection Using Laser-Powered Coils	3
M. Manuel	General Atomics	Characterization of Early-Stage, Quasi-Parallel, Collisionless-Shock Formation	4

Table I: During FY22, three LaserNetUS Cycle-3 projects (shaded cells) completed 34 target shots over four shot days and five new LaserNetUS projects selected from the Cycle-4 solicitation were approved with a total of five shot days for experiments on OMEGA EP in FY23 (continued).

Principal Investigator	Institution	Title	LaserNetUS beam-time cycle
I. Oleynik	University of South Florida	Exploring Metastability and Phase Transitions in Dynamically Compressed Amorphous Carbon	4
D. Schaeffer	Princeton University (now at University of California, Los Angeles)	Dependence of Particle Acceleration on Shock Structure in Magnetized Collisionless Shocks on OMEGA EP	4
M. Wadas	University of Michigan	Observation and Scaling of Vortex Rings Ejected from Shock-Accelerated Interfaces	4
J. Wicks	Johns Hopkins University	*In Situ* X-Ray Diffraction Study of Shock-Compressed Diamond: Improving Equation-of-State Models Through Data-Driven Experimental Designs	4

Controlling the Energy of Relativistic Positron Jets

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[3]Laboratory for Laser Energetics, University of Rochester
[4]University of Michigan
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Creating a platform to study the physics of relativistic electron–positron plasmas requires control over the key parameters of laser-driven positron jets. Specifically, the positron beams produced by kilojoule-scale, 10-ps laser pulses focused on gold targets are too high in energy for efficient interactions at the electron and positron densities that we are currently able to achieve. The energy of generated positrons is dominated by their acceleration in the sheath field on the back surface of gold-disk targets. Here we examined two approaches for controlling the energy of these positron jets: (1) we increased the target diameter and (2) we generated a plasma using a long-pulse beam on the back surface of our primary target. Both approaches were designed to reduce the accelerating sheath field. Initial results indicate successful reduction in the average measured positron energy using both approaches. Figure 1 shows how the distribution of positron energies decreased for larger target diameters, following model expectations.

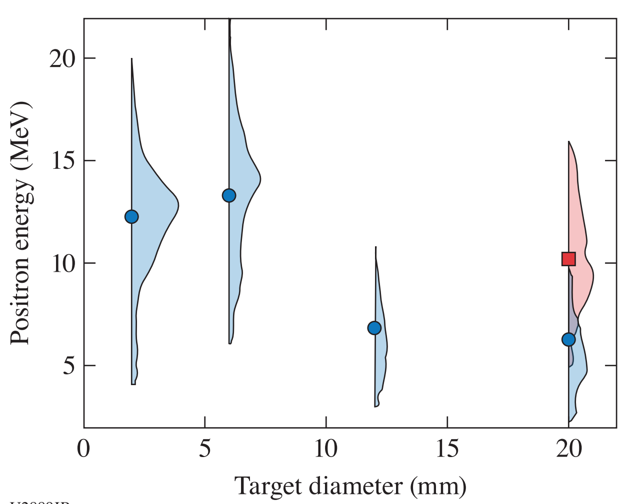

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Figure 1
Measured positron energy distributions as a function of target diameter. Blue points are taken for targets under the same conditions. The red square corresponds to data taken with a microwire-coated target, producing enhanced yield and less energy reduction.

Initial analysis suggests scaling behavior follows expectations and that both mechanisms can, in principle, be used for energy control. The addition of microwires at the target front surface enhanced yield and reduced the effectiveness of the sheath field reduction.

Understanding Temperature Dependence of Iron Strength at High Pressure with Ramped Compression on OMEGA EP

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A fundamental material property—strength—is studied under high-stress and -temperature loading conditions (150 GPa, thousands of K) relevant to the interior of rocky planetary bodies. Experiments on OMEGA EP are well suited to probe this region of plastic deformation to better understand iron strength under these extreme conditions and to test physics-based constitutive models. Hydrodynamic simulations were used to design unique laser pulse shapes to probe iron samples at constant, high pressure, and different temperatures.

In the experiment, the Rayleigh–Taylor instability was used to infer the material's strength by analyzing the amount of growth of preimposed ripples and comparing to growth simulations. The VISAR (velocity interferometer system for any reflector) diagnostic was used to measure the pressure incident on the iron after laser irradiation of the custom 30-ns laser pulse. Radiography was used to image ripple iron samples at specific times (Fig. 2).

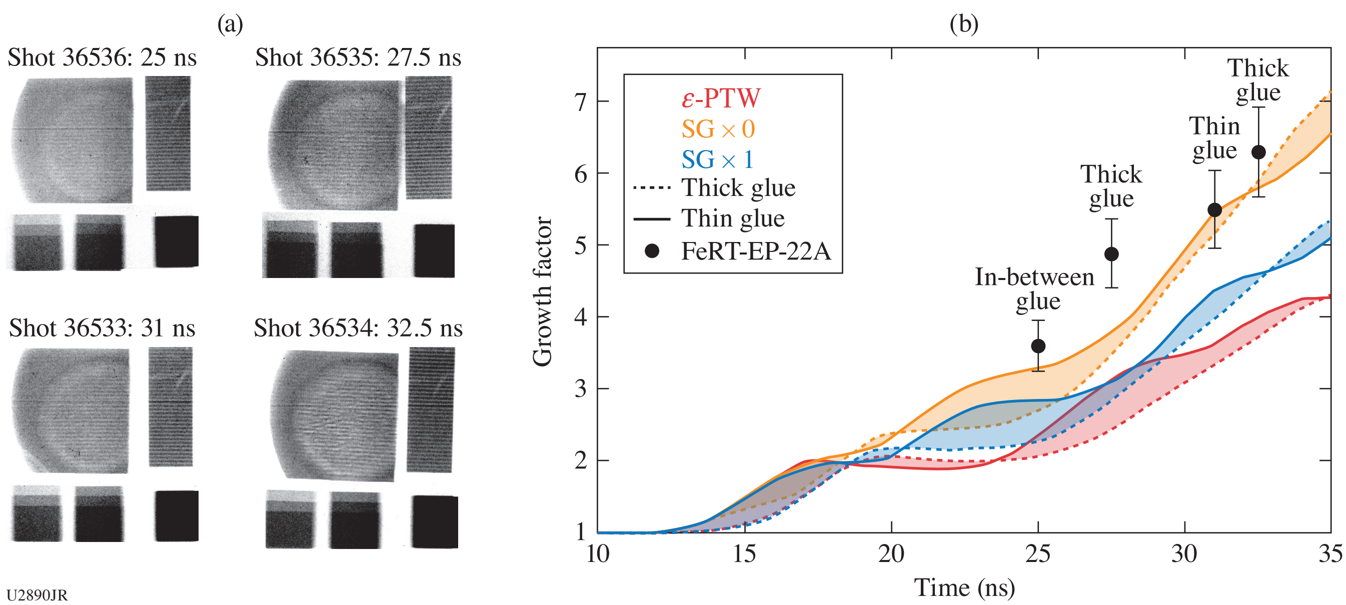

Figure 2
(a) High-quality radiographs taken at different delay times. The large, rippled sample shows clear evidence of laser spot size. Ripple material on the right side of each image is undriven material used for growth factor calculation. Steps and knife-edge on the bottom of each image are calibration metrics. (b) Growth factor predicted from hydrodynamic simulations compared to experimental data. Curves represent varying glue thicknesses according to target metrology. Data are consistent with low strength. PTW: Preston–Tonks–Wallace;[1] SG: Steinberg–Guinan.[2]

High-pressure, high-temperature shots (200 GPa, ~4000 K) were taken during one OMEGA EP shot day and preliminary results found that growth is larger than is predicted by the Preston–Tonks–Wallace[1] and Steinberg–Guinan[2] strength models. This suggests that iron is weaker than expected, contradictory to recent ultrahigh-pressure iron experiments at the National Ignition Facility. The differences between the experimental and simulated growth could be attributed to: (1) the high temperature allows for easier deformation that the models and simulations are not accurately predicting or (2) the iron is unexpectedly melting. Further post-shot analysis and post-shot simulations will confirm results. An additional shot day is needed to probe the high-pressure, low-temperature regime of iron strength not discussed here.

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Particle Acceleration Mechanisms in Magnetically Driven Reconnection Using Laser-Powered Capacitor Coils

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Magnetic reconnection is a ubiquitous astrophysical process, whereby magnetic energy is rapidly converted into plasma kinetic energy in the form of bulk flow, thermal energy, and nonthermal particles. The latter is often regarded as an observational signature of reconnection, which can be a more-efficient particle accelerator than other processes such as collisionless shocks. In the past ~six years, our team has developed a platform to study acceleration of nonthermal electrons from magnetic reconnection at low plasma beta using UV laser-powered capacitor coils.[3] For the first time, nonthermal electrons accelerated by the reconnection electric field have been measured.[4] Using the short-pulse laser-powered capacitor coils newly developed by our group, we extended our platform to a new regime with tripled magnetic-field strength to achieve particle acceleration by magnetically driven axisymmetric reconnection with one order of magnitude higher energy. In FY22, under the LaserNetUS program, we successfully performed two shot days on OMEGA EP. The proton data show a clear signature of current sheet formation and evolution. Particle acceleration was also observed. Detailed analyses and particle-in-cell (PIC) simulations are underway.

The experimental setup shown in Fig. 3 built on our previous experiments using the short-pulse IR lasers. The main target is composed of two Cu plates with a laser entrance hole in the front plate, connected by a pair of parallel U-shaped coils. OMEGA EP backligher Beam 2 was used to irradiate the back plate center at a 45° incidence angle, thereby positively charging up the back Cu

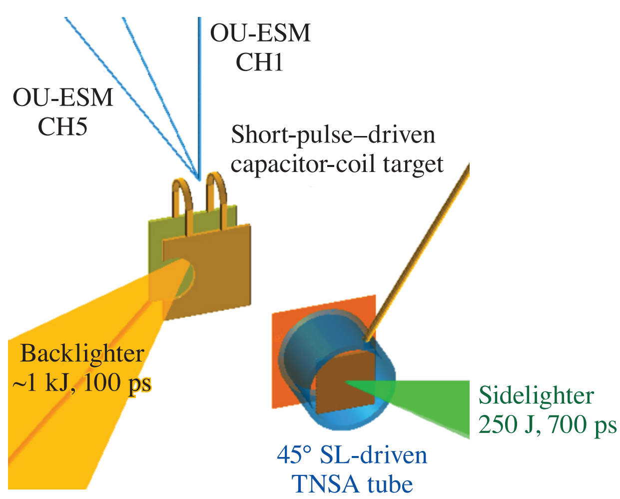

Figure 3
Experimental setup. The OMEGA EP BL was focused onto the back plate, positively charging it up. The resulting voltage difference between the back and front plate drives currents in both coils, creating reconnection. Ultrafast protons generated by the SL probed through the coils and was collected by a proton film back held by TIM-14. For shots aiming for particle acceleration, proton radiography was turned off, and OU-ESM, EPPS, and SC-ESM's were fielded at TIM-11, TIM-12, TIM-10, and TIM-13 to monitor particles at various angles.

plate. The voltage difference between the back and front plate drove the currents in both coils, creating reconnection in between. Face-on proton radiography was used to probe through the coils, capturing the magnetic-field topology change and associated fine structures. We positioned multiple particle spectrometers such as the Osaka University Electron Spectrometer (OU-ESM), single-channel electron spectrometer (SC-ESM), and electron–positron–proton spectrometer (EPPS) in TIM-10 to TIM-13 (ten-inch manipulators) to capture the energetic particles accelerated tangentially along the X-line, and compare the particle spectra at various distances and angles with respect to the reconnection region.

Figure 4 presents two examples of the proton images taken at 1 ns and 3 ns, with respect to the beginning of the sidelighter (SL) drive. Compared to the proton images obtained with UV lasers, these proton images see almost no plasma effects around the coils. Two prolate voids corresponding to magnetic-field generation around the coils are observed. In addition, at 3 ns a center feature developed between the voids corresponding to current sheet formation.

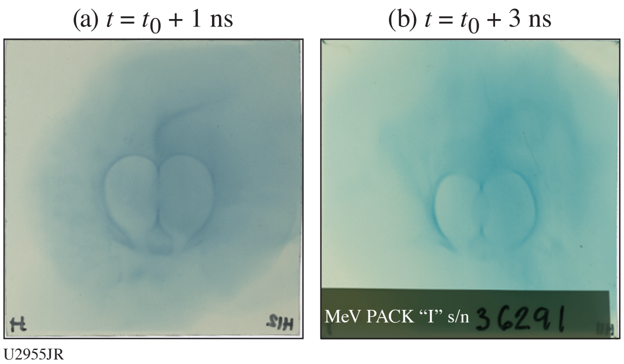

Figure 4
Photon radiographs taken at (a) 1 ns and (b) 3 ns with respect to the beginning of the SL.

Figure 5(a) presents the OU-ESM data for the reconnection case and Figs. 5(b) and 5(c) present two no-reconnection cases. The no-reconnection case had only one coil (either left or right), thereby no reconnection occurred. Compared to the data from the no-reconnection cases, the electron spectra for the reconnection case had much higher signals and a significant bump at ~80 keV is clearly seen. These data will be compared with in-depth PIC simulations as well as our previous observations using the UV drivers.

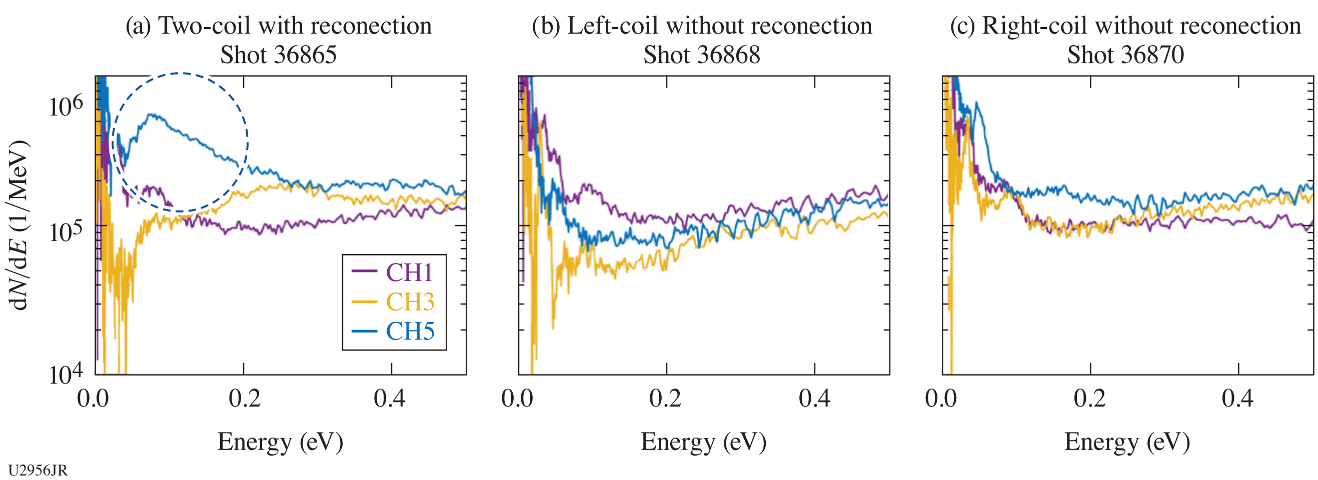

Figure 5
(a) OU-ESM data for the reconnection case and [(b),(c)] two no-reconnection cases.

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