White Paper
FORWARD user facility proposal for High Energy Density science,
(Fundamental Optical Research With Advanced x-Radiation Diagnostic)

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A. Mission Need and relation to Fusion Energy Sciences Goals

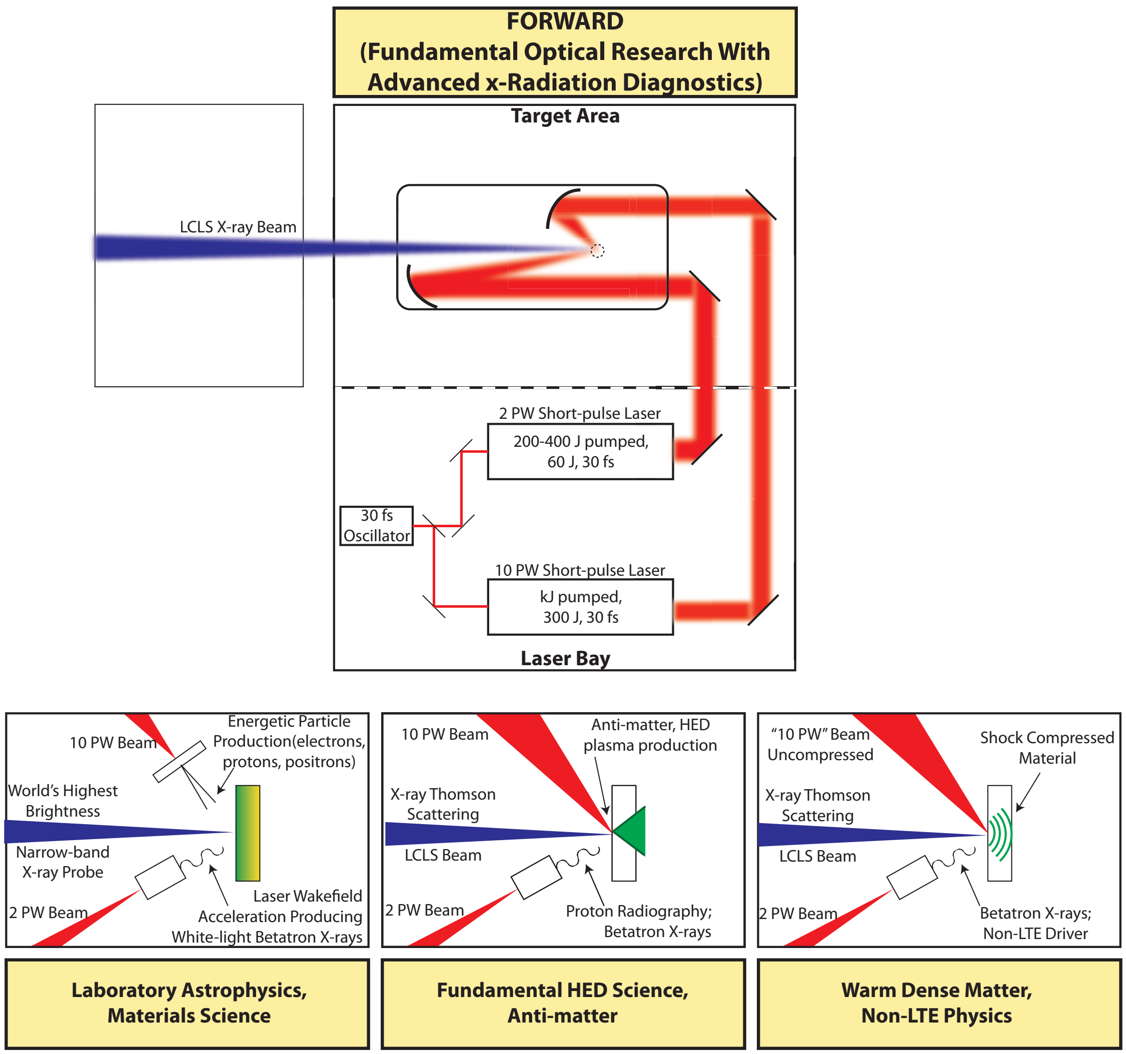
We propose a new user facility that will combine the existing world-class experimental probing capabilities of the Linac Coherent Light Source (LCLS) with new ultrahigh power multiple peta-watt lasers to directly address the research goals defined by OFES. Two multiple peta-watt lasers will allow creating conditions in the areas of high energy-density science, warm dense matter, laboratory astrophysics, and material science whose physical properties will be measured in exquisite pump-probe experiments using LCLS x-rays. The facility will provide a novel combination of newly built high-repetition rate optical lasers with the existing world-brightest x-ray source. The repetition rate and pulse width will provide a natural match to the LCLS x-ray capabilities allowing pump-probe experiments with very high data throughput with shot rates ranging from 1 shot/min to ~10 Hz. Thus, this facility will provide the experimental capability needed to support a large user community for world-class experimental discoveries and to answer fundamental physics questions in areas defined as high priority by Fusion Energy Science. In particular, FORWARD will tackle *grand challenges in high energy density plasma science to explore the feasibility of the inertial confinement approach as a fusion energy source, to better understand our universe, and to enhance national security and economic competitiveness [see Ref. 1-4]*.

Distinct from existing and planned high-energy density science facilities, the ability to perform pump-probe experiments at high repetition rate will transform our understanding of matter at high energy densities *[5]*. The unique combination will, for the first time, allow investigations of the properties of materials when exposed simultaneously to ultra-bright photon and particle flux conditions that approach those found at the most extreme astrophysical locations in the universe or those found in fusion conditions.

FORWARD will be the first user facility with multiple peta-watt laser capability filling an urgent need for the high-energy density science community and providing competitive research opportunities that will go beyond the capabilities at future scoped facilities in Europe (ELI, LOA) and Asia. The nature of discovery-driven research that will be performed at FORWARD is very well aligned with several DOE reports such as in P*hysics 2010: Plasma Science, advancing knowledge in the national interest, 2007* or the *FESAC HEDLP report 2009.* Importantly, the operation as a user facility, a well-tested mode at SLAC, will assure broad academic access that will be facilitated by the fact that SLAC has an ongoing program attracting world-renowned scientists to SLAC.

B. Project Purpose

High Energy Density conditions will be produced by the simultaneous exposure of matter to the high fluence of energetic particles (protons, electrons) and a broadband x-ray spectrum both delivered by two independent ultra-high power short-pulse laser experiments. At the 1 PW-level, high-energy density plasmas approaching giga bar pressures will be produced while with 10 PW-radiation pressures above one giga bar, relativistic plasmas and antimatter plasmas will become possible. Unique is the capability to probe these micron-scale plasmas with first principles x-ray scattering techniques using LCLS. Thus, the unprecedented high-energy density conditions will be produced at a physical scale length that is matched to the LCLS probe and consequently motivating the use of multiple peta-watt laser drivers consistent with a budget estimate of $123 million. The figure shows a sketch of the FORWARD facility. A laser building will be in close proximity to one existing LCLS end station so that two PW laser beams can be combined with the LCLS x radiation in one target area.



Current peta-watt-class laser experiments have primarily occurred at laser powers close to one peta-watt. They have indicated remarkable capability to create conditions with high versatility for laboratory scale research. Since most facilities only consist of single laser beams contemporary research has focused on demonstrating the production of energetic particles, antimatter, and x-rays. For example, experiments have produced proton and ion beams of order 100 MeV energy, mono-energetic electron beams above 1 GeV of energy, and antimatter (positrons) due to pair productions in high-Z targets. This intense flux of particles has been complemented by research on ultrafast (~50 fs) emission of bright and collimated broadband betatron x-rays in excess of 10 keV that are now becoming routine for radiography application in multiple laboratories.

Matter driven into high-energy density science conditions will be probed with angularly, spectrally and temporally resolved x-ray scattering from the LCLS beam. The ongoing development of these techniques has resulted in accurate measurements of the microscopic conditions namely electron and ion temperature, mass and electron density, and long-range collective properties. In addition, x-ray scattering will provide the dynamic structure factor and refractive index thus providing material structure and the physical properties. This information will enable critical experimental tests of state of the art modeling using hydrodynamics, particle in cell, molecular dynamics and density functional theoretical calculations in conditions of critical importance for new scientific discoveries.

C. Schedule and Cost

FORWARD is ready to initiate construction. The facility will use existing laser technology that is presently delivered for two multiple peta-watt laser projects in Europe. There are two competing technologies that we will evaluate and that both are ready for delivering high-repetition rate ultra high-power lasers. These are the flash lamp pumped amplifier systems from Apollon and the diode-pumped amplifiers from Lawrence Livermore National Laboratory. For FORWARD, the technology will be scaled up to the 10 PW level. The combination of highest power lasers with LCLS will provide the unique probing capability for highly visible, high-impact advances in the area of high energy density science.

For the first stage, the existing large amplifier technology will provide 200 to 400 J of pump laser energy in the infrared spectral range. Combined with standard short pulse laser components they will provide up to 60 J in 30 fs with 2 PW after compression. FORWARD will consist of two short pulse beams, one at 2 PW for ultrafast broadband 10-20 keV betatron and 100 keV Compton radiation, and the second at 10 PW for energetic ions (>100 MeV), high-energy density plasmas above giga bar pressures, and production of anti-matter plasmas. The second arm will require one additional high repetition rate kilojoule pump laser to achieve 300 J, 30 fs, 10 PW after compression for target experiments.

The cost are estimated as follows

- Short Pulse Laser system $10M x 2 = $20M
- 200-400 J, 0.01-10 Hz amplifier $15M x 2 = $30M
- 1kJ, 0.01-10 Hz amplifier $25M
- Engineering cost $8M
- Laser Hall and Transport $20M
- Radiation Shielding $10M
- Experimental hall and tunnel modifications $5M
- LCLS transport and focusing $5M

- Total $123M

The cost estimates are fairly mature and are based on information about the 2 European multi-peta watt laser projects. The kilojoule pump laser would need additional development. The engineering cost for combining existing amplifier module technology to deliver the required pump laser energy are estimated at $8M. A new laser building and radiation shielding of an end station instrument will be required. In addition, LCLS transport and focusing modifications will allow higher x-ray probe intensities on target. It is also considered to operate LCLS with a fast switching mirror that would allow to continuously delivering an x-ray pulse into the end station at 1 shot/min without significantly affecting other end station experiments. This alternate mode of operation may allow significantly more user experiments than currently performed.

D. Organization of FORWARD

SLAC will have lead responsibility for execution and nominal hosting of the FORWARD project. The Lawrence Livermore National Laboratory and Lawrence Berkeley National Laboratory will provide support including technical leadership in specific technical areas of the project. A project management organization will be formed within the SLAC organization, reporting to the Department of Energy through the SLAC Director.

The Office of Fusion Energy Sciences (OFES) in the DOE's Office of Science has the responsibility for the programmatic and technical oversight of the project. The area manager of the DOE Stanford Site Office will assign a DOE project manager having primary responsibility to ensure that the project is properly managed by SLAC and that its technical objectives are met within the baseline cost and schedule.

E. References

[1] Frontiers in High-Energy-Density Physics: The X Games of Contemporary Science, 2003 (http://www.nap.edu/catalog.php?record_id=10544)

[2] Report of the Interagency Task Force on High-Energy-Density Physics (Chairs: C. Keane, D. Kovar), National Science and Technology Council, Committee on Science, Interagency Working Group on the Physics of the Universe. (http://www.whitehouse.gov/sites/default/files/microsites/ostp/report_of_the_interagency_task_f orce_on_high_energy_density_physics.pdf).

[3] Fusion Energy Sciences Advisory Committee report on Advancing the Science of High Energy Density Laboratory Plasmas, Chair: Riccardo Betti (http://science.energy.gov/~/media/fes/fesac/pdf/2009/Fesac_hed_lp_report.pdf)

[4] Report of the 2009 Workshop on Basic Research Needs for High-Energy-Density Laboratory Physics, Chairs: Robert Rosner and David Hammer. (http://science.energy.gov/~/media/fes/pdf/workshop-reports/Hedlp_brn_workshop_report_oct_2010.pdf)

[5] S. H. Glenzer and R. Redmer, Rev. Mod. Phys. 81, 1625 (2009).