Snowmass 2021 Letter of Interest: The ZEUS high intensity laser user facility for research into laser driven particle acceleration

Karl Krushelnick, Igor Jovanovic, Carolyn Kuranz, Anatoly Maksimchuk, John Nees, Alec G. R. Thomas, Louise Willingale

The Gerard Mourou Center for Ultrafast Optical Science, University of Michigan, Ann Arbor, Michigan 48109, USA

The Center for Ultrafast Optical Science (CUOS) at the University of Michigan (UM) is constructing a new National Science Foundation funded high power laser facility for the US scientific community, having an open and transparent external review panel for facility access and 30 weeks/year dedicated to external user experiments. Construction of this facility follows along from the recommendations of a recent National Academy Report on "Opportunities in Intense Ultrafast Lasers: Reaching the Brightest Light (2018)" which advocates for the construction of mid-scale university based intense laser facilities in the US. Such a facility will provide new capabilities for exploring plasma based accelerator concepts, experiments relevant to high-energy astrophysical phenomena and new particle sources for detector development.

The past two decades have witnessed the development of revolutionary light sources having the unprecedented ability to control matter. The Center for Ultrafast Optical Science at UM has been at the forefront in the development of this high-power laser technology, including the world-leading ultrashort pulsed, high intensity laser facility, HERCULES, founded by Gérard Mourou (Physics Nobel Prize 2018). The facility to be constructed at CUOS will build on the success of HERCULES to create a new facility, **ZEUS**, a Multi-Beam 3 PetaWatt laser system that would provide unique and world-leading capabilities for the US scientific community. The name ZEUS (**Z**ettawatt-**E**quivalent **U**ltrashort pulse laser **S**ystem) refers to the interaction of a PW laser pulse colliding with a GeV energy electron beam that may be generated by one of its two beamlines. This geometry provides the equivalent of a "Zettawatt" power laser interaction (10^{21} Watts) in the rest frame of the electron beam and will allow the first systematic exploration of relativistic plasma in quantum critical fields, similar to extreme astrophysical objects.

The proposed ZEUS system will have three main modes of operation, either for experiments using a combined single 3 PW beamline or for dual beam 2.5 PW and 500 TW experiments or experiments at 500 TW at 5 Hz. A nsec 70 J shock driving beamline for High Energy Density Physics investigations will also be available. After completion in 2023 the ZEUS laser system will operate as an open facility for US researchers in high field science as well as for the wider international research community. It will be the highest-power laser system in the US and will be among the highest-power lasers worldwide for the next decade.

The multi-beam experimental configuration will enable flexibility for *Advanced Accelerator Concepts* development as part of the *Accelerator Frontier,* in addition to

experiments in relativistic pair-plasma for the *Cosmic Frontier* and test facilities for the *Instrumentation Frontier*. The 3 PW laser will be the most powerful in the US for experiments in laser wakefield acceleration. The multi-beam configuration will allow flexible experimental configurations for exploring new diagnostic and injection concepts. Laser interactions with laser driven GeV electron beams will be possible at intensities approaching 10^{23} W/cm^2. In the rest frame of an electron, the laser electric field will greatly exceed the QED critical field, which will allow exploration of fundamental yet unanswered questions regarding non-linear QED in relativistic plasmas, including non-perturbative quantum radiation reaction and electron-positron pair production mechanisms. Further experiments enabled by this facility will include pump-probe experiments using fsec x-rays as a probe of dynamics on ultra-short timescales, the production of GeV ion beams, the generation of instabilities in electron-positron jets, the exploration of vacuum polarization effects and the production of sources of other particles such as pions and muons. The high-energy particle beams could provide sources for calorimeter testing that are otherwise scarcely available for high energy instrumentation development.

CUOS was founded in 1990 and has been an interdisciplinary research center for more than 25 years focused on the use of ultra-short laser pulses in science and technology. There have been major impacts to society from this research, which has involved the training of research students, the licensing of patents and the formation of many highly successful spin-off companies. The ZEUS initiative is also likely to have local and national economic impact through creation of new job positions for highly skilled scientists and engineers, and is likely to attract talent to these sites both internally and externally to the US and will also likely lead to the formation of new high tech companies.