- IFSA2025 –

Proton Fast Ignition: High gain concept for Inertial Fusion Energy

F. N. Beg [(1)], M. Bailly-Grandvaux [(1)], S. Bolanos[(1)], P. Samimy [(1)] and J. Kim[(1)]

[(1)] Center for Energy Research, University of California San Diego, CA 92093, USA

Recent demonstration of ignition on the National Ignition Facility has generated significant interest and excitement surrounding fusion's potential as a source of clean energy. However, the product of driver efficiency and target gain needs to be > 100 for inertial fusion energy (IFE) to become economically viable [1]. Fast Ignition is an advanced inertial confinement fusion concept that promises high gain by separating the compression and ignition phases thus lowering driver threshold energy [2]. Proton beams are especially well suited to FI because they can isochorically heat the assembled fuel [3]. Furthermore, inherently low emittance and simplicity of focusing mean that exceptionally high peak beam densities can be achieved from the laser-driven proton source. We have developed a platform on the OMEGA-EP laser facility to investigate proton beam generation and isochoric proton heating using a realistic Proton Fast Ignition (PFI) target configuration. The PFI target features a hemisphere and a cone to focus protons and shield the proton target from preheat and radiation. The Target Normal Sheet Acceleration mechanism-driven proton beam heats a copper sample. The generation of the proton beam and the proton heating was characterized through a suite of diagnostics. A high-resolution streaked spectrometer (HiResSpec) tuned to copper Kα lines provided bulk temperature measurements, revealing temperatures exceeding 100 eV in under 50 ps. Supporting Particle-in-cell simulations indicate a three-phase heating process of the Cu sample: initial electron preheats, followed by proton-driven heating, and finally a contribution of heavy ions. We also present the results from the first integrated proton-FI experiments performed on OMEGA. In these experiments, the intense proton beam is focused and guided into a copper-doped CH spherical capsule imploded by 54 long-pulse beams, delivering a total compression energy of about 18 kJ. Radiation-hydrodynamics and hybrid-PIC simulations are compared with experimental data, with particular attention to the effects of compression on proton acceleration and transport. Together, these advances establish a new framework for evaluating the robustness of the proton fast ignition concept and advance the experimental study of warm dense matter.

References

[1] W. Trickey *et al.*, Phys. Plasmas **31**, 012702 (2024)

[2] S. Atzeni, Phys. Plasmas **8**, 3316 (1999); M. Roth *et al.*, Phys. Rev. Lett. **86**, 486 (2001); M. H. Key, Phys. Plasmas **14**, 055502 (2007); J.-C. Fernández *et al.*, Nucl. Fusion **49**, 065004(2009).

[3] K. Bhutwala *et al.*, Phys. Rev. E **105**, 055206 (2022).

The beam time on OMEGA was supported through the National Laser Users' Facility (NLUF) program with support from the U.S. DOE/NNSA for the University of Rochester under Award Number DE-NA0004144. The work was supported by the U.S. Department of Energy's (DOE) Office of Science (SC) Fusion Energy Sciences (FES) program under DE-SC0024415: the LaserNetUS initiative at OMEGA-EP. This work was also partially supported by Shao-Chi and Lily Lin Chancellor's Endowed Chair funds.