Enhancement of ion acceleration from transparency-driven foils demonstrated at two ultra-intense laser facilities

M. Nishiuchi [1], N. P. Dover [1,3], A. Kon [1], C. Liu[1], Ko. Kondo[1], H. Kiriyama[1], H. Sakaki[1,2], H. F. Lowe[1], J.K. Koga[1], T. Miyatake[1,2], I. Takemoto[1,2],
[1] *Kansai Photon Science Institute (KPSI), National Institutes for Quantum Science and Technology (QST), Kizugawa, Japan.*
[2] *Interdisciplinary Graduate School of Engineering Sciences, Kyushu University, Japan.*
E.J. Ditter[3], G.S. Hicks[3], Z. Najmudin[3],
[3] *John Adams Institute for Accelerator Science, Blackett Laboratory, Imperial College London, U.K..*
T. Ziegler[4], S. Assenbaum[4], C. Bernert[4], F-E. Brack[4], S. Bock[4], T. Cowan[4], M. Garten[4], L. Gaus[4], I. Goethel[4], T. Kluge[4], S. Kraft[4], F. Kroll[4], J. Metzkes-Ng[4], T. Pueschel[4], M. Rehwald[4], M. Reimold[4], H-P. Schlenvoigt[4], M. Umlandt[4], U. Schramm[4], K. Zeil[4]
[4] *Helmholtz-Zentrum Dresden-Rossendorf, Germany.*
nishiuchi.mamiko@qst.go.jp

Laser driven ion beams are attractive to many fields of applications because of their unique features, different from those of conventional accelerator beams. One of the applications is a next generation ion accelerator. Although extensive attempts have been carried out around the world to produce better quality beams in a controllable manner, there are still issues for improvement, such as high energy ion generation, controllability, and so on.

As is well known, the temporal contrast condition of the laser is vital for the ion acceleration performance. We have been continuously improving temporal contrast condition of J-KAREN laser system at KPSI and Draco-PW system at HZDR independently for pursuing better ion acceleration performance in a controllable manner. However, before starting the joint project, the ion acceleration performance in both systems based on Target Normal Sheath Acceleration (TNSA) mechanism was different even though the basic laser parameters are very similar. Such an issue should be solved for any applications of laser-driven ion beams. Additionally, a favorable ion energy scaling on laser energy, power, and intensity is not expected with the TNSA mechanism, because the laser energy coupling to thermal electrons is not efficient.

We, KPSI and HZDR, have joined forces to optimize ion acceleration performance in a controllable manner by using J-KAREN-P and DRACO-PW [1]. We have duplicated the ion acceleration performance by controlling the temporal pulse condition in both systems, demonstrating energetic light ion acceleration (> 60 MeV proton and > 30 MeV/u C6+) from plastic targets. This acceleration regime was also extended to high-Z ions at J-KAREN-P, demonstrating highly charged (Z*~45 of Ag and Z*~65 of Au) energetic heavy ions (> 20 MeV/u of Ag and ~ 10 MeV/u of Au) from metal targets [2].

Combined hydrodynamic and 3D particle-in-cell simulations revealed that strong acceleration takes place in a strong transient space-charge field which is formed at the onset of relativistic transparency when the main pulse interacts with a target whose density profile has been tailored by the laser temporal components preceding the main pulse.

Insight gained in this work has been crucial in the design of follow up experiments at the DRACO-PW yielding even higher proton energies.

Acknowledgments
Kakenhi Grant No. 16K05506, Grant No. 20H00140, Grant No. 21KK0049, Grant No.22H00121, JST PRESTO Grant No. JPMJPR16P9, QST President's Strategic Grant (QST International Research Initiative (AAA98) and Creative Research (ABACS)

References

[1] N.P. Dover and T. Ziegler et. al., Light Sci. Appl., *in press* (2023).
[2] M. Nishiuchi et. al., Phys. Rev. Res., 2, 033081, (2020).