5th Asia-Pacific Conference on Plasma Physics, 26 Sept-1Oct, 2021, Remote e-conference

Enhancement of the accelerated ion beam quality by controlling the temporal profile of the high intensity short pulse laser system

M. Nishiuchi[1], N. P. Dover[1], H. Sakaki[1,2], H. F. Lowe[1], A. Kon[1], Ko. Kondo[1], H. Kiriyama[1], Ki. Kondo[1], M. Kando[1], T. Miyatake[2], Y. Watanabe[2], E.J. Ditter[3], G.S. Hicks[3], Z. Najmudin[3], T. Ziegler[4], M. Garten[4], I. Goethel[4], S. Assenbaum[4], C. Bernert[4], S. Bock[4], M. Rehwald[4], T. Pueschel[4], M.E.P. Umlandt[4], T. Kluge[4], U. Schramm[4], K. Zeil[4]

[1]Kansai Photon Science Institute, QST, Japan:

[2]Kyushu University, Japan:

[3]Imperial College London, UK:

[4]Helmholtz-Zentrum Dresden-Rossendorf, Germany:

nishiuchi.mamiko@qst.go.jp

High power femtosecond laser pulses focused to ultra-high intensities exceeding 10^{21}W/cm^2 onto solid density targets can produce highly charged energetic ion beams which attract many fields of applications because of their unique characteristics including the possibility of the significant downsizing of the system. However, the controllability of the beam, which is a necessary condition for applications, is not well established. One of the major reasons of this is the unperfect characterization of the on-shot experimental parameters, such as laser spatial and temporal profiles. The characterization of these parameters, especially for the PW-class high intensity laser systems are themselves cutting-edge research themes. The methodologies for evaluating the laser parameters vary depending on each laser facility. This leads to the situation that the ion acceleration performance in one laser facility cannot be easily reproduced by the other laser facilities.

We, therefore, joined forces to set compatible experimental conditions at the J-KAREN-P laser at KPSI and the Draco PW laser at HZDR, two PW-class world leading laser systems. The compatible experimental conditions include the cross-calibrated laser parameters and charged particle diagnostics. In particular, we focused on the evaluation of the on-shot temporal pulse profile and carefully adjust those at both laser systems from ~100 ps before the main pulse. By using the same target, we successfully re-produce the ion acceleration performances at both laser systems, showing the maximum proton energies of > 50 MeV and carbon energies of > 30 MeV/nucleon by a modest laser energy of 10 J which is focused on ~250 nm plastic targets. Transmitted light and electron diagnostics show that this optimum thickness is related to the first onset of relativistic transparency.

Hydrodynamic and 3D particle-in-cell simulation reveals that the laser temporal condition, especially the ps-rising edge, plays an important role in creating an optimum target density profile. Strong acceleration takes place when the onset of the relativistic transparency matches the timing of the main pulse peak arrival onto the “prepared” target. A transient strong charge separation field is generated when the electrons are blown away by the laser pondermotive force. Even with a modest laser contrast condition from both laser systems without using plasma mirrors, the expansion of the plasma is not so significant to disrupt the acceleration of particles to high energies within the short life time of the acceleration field.

These results show that slight differences seen in other parameters of two laser systems, such as focus size, laser energies and pulse duration, etc, have a far smaller impact on to the ion acceleration performance than the laser temporal pulse profile. These results therefore give us a bright prospect for the establishment of laser-driven ion accelerators.