Ion acceleration and γ-ray beams generation in low density targets using ultra-high intensity lasers

E. d'Humières[1], M. Lobet[1,2], X. Ribeyre[1], L. Gremillet[2] and V. Tikhonchuk[1]

[1] *Univ. Bordeaux – CNRS - CEA, CELIA, Talence, France*

[2] *CEA/DAM-DIF, Arpajon, France*

Corresponding author: dhumieres@celia.u-bordeaux1.fr

Abstract

Recent theoretical and experimental studies suggest the possibility of enhancing the efficiency and ease of laser acceleration of protons and ions using underdense or near critical plasmas through electrostatic shocks. Scaling shock acceleration in the low density regime to ultra high intensities is a challenge as radiation losses and electron positron pair production change the optimization of the shock process. Using large-scale Particle-In- Cell simulations, the transition to this regime in which intense beams of relativistic ions and of MeV photons can be produced is investigated. The application of these beams to high energy laboratory astrophysics is discussed.

The intense research being conducted on sources of laser-accelerated ions and their applications, e.g. radiography and the production of warm dense matter (WDM), is motivated by the exceptional properties that have been demonstrated for proton beams accelerated from planar solid targets, such as high brightness, high spectral cut-off, high directionality and laminarity, and short duration (~ps at the source). These ion sources are very promising for a wide range of applications [1,2] ranging from the production of radio-isotopes and the testing of mechanisms of extreme energy particle production in gamma-ray bursts, but also to improve prospects for the necessary gantry for proton therapy or for fast ignition of inertial confinement fusion targets with high gain.

The results in [3,4] using low density targets suggest the possibility of enhancing the efficiency and ease of laser acceleration of ions compared to what has been achieved up to now using solid foils. Recently, important progress has been achieved in the production of the short near-critical density gas jets required in this regime [5]. Scaling laser ion acceleration in the low density regime to ultra high intensities ($>10^{22}$ W/cm^2) is a challenge as radiation losses and electron positron pair production change the optimization of the acceleration process. Using large-scale Particle-In-Cell simulations including these effects, we have investigated and modeled the transition to this regime in which intense beams of relativistic ions (see Fig.1) and a large number of MeV photons (see Fig. 2) can be produced.

These relativistic ion beams are of great interest for high-energy laboratory astrophysics as they could be used to prepare the first relativistic collisionless shocks experiments in the laboratory using ultra high intensity laser systems like Apollon or ELI. The study of the development of relativistic collisionless shocks is crucial to test specific astrophysical scenarios (for instance for Gamma Ray Bursts models and particle acceleration models in Supernova Remnants). The γ-ray beams produced can be used to study the Breit-Wheeler process in the laboratory [6].

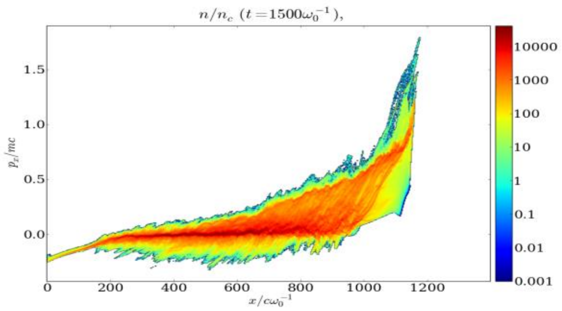

Fig. 1. Proton phase space after 1500 ω_0^{-1} for I = I=10^{23} W/cm^2 (right) for a 2 n_c, 190 μm long cos^2 target. The laser comes from the left.

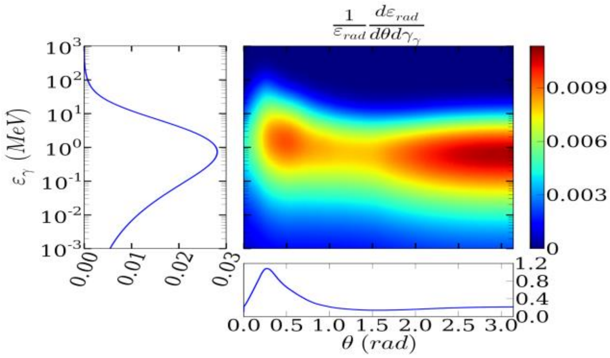

Fig. 2. Spectral and angular distribution of the emitted photon energy in the interaction of a laser pulse at 10^{23} W/cm^2 with a 4 n_c, 80 μm thick hydrogen gas jet

References

[1] E. d'Humières (2012). Ion Acceleration by High Intensity Short Pulse Lasers, *Laser Pulses - Theory, Technology, and Applications*, Prof. Igor Peshko (Ed.), ISBN: 978-953-51-0796-5, InTech, DOI: 10.5772/46137.

[2] A. Macchi et al., *Rev. Mod. Phys.* **85**, 751 (2013).

[3] E. d'Humières et al., *Plasma Phys. Control. Fusion* **55,** 124025 (2013). M. Gauthier et al., *Phys. Plasmas* **21**, 013102 (2014).

[4] E. d'Humières et al., *J. Phys. Conf. Ser.* **244,** 042023 (2010). E. d'Humières et al., *Phys. Plasmas* **20,** 023103 (2013).

[5] F. Sylla et al., *Rev. Sci. Instrum.* **83,** 033507 (2012).

[6] X. Ribeyre et al. arXiv:1504.07868 (2015).