Laser ion acceleration with low density targets: a new path towards high intensity, high energy and high current ion beams

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Intense research is being conducted on sources of laser-accelerated ions and their applications, motivated by the exceptional properties of these beams: high brightness, high spectral cut-off, high directionality, laminarity, and short duration (~ps at the source). It was recently shown experimentally that a promising way to accelerate ions to higher energies and in a collimated beam is to use under-dense or near-critical density targets instead of solid ones. In this case, volume effects dominate, enhancing the laser-to-proton energy conversion, and allowing to reach high ion energies with a high number of accelerated ions. This scheme also leads to less debris than solid foils and is adapted to high repetition lasers. Under certain conditions, the most energetic protons are predicted to be accelerated by a collisionless shock mechanism that significantly increases their maximum energy.

The transition between various laser ion acceleration regimes depending on the density gradient length (controlled by the delay between the lasers) was studied at LULI in May 2011 using a two-laser setup. A first ns pulse was focused on a thin target to explode it and a second laser (350 fs pulse duration, high intensity) was focused on the exploded foil. Protons with energies close to the ones reached using solid targets were obtained for various exploded foil configurations with ~5 J of laser energy. As this regime scales well with laser energy, new experiments were performed in 2012 with more laser energy (~180 J) on the LLNL Titan laser with a similar setup. In this high energy regime, protons with energies significantly higher than the ones reached for solid targets were obtained while keeping a good beam quality. These results demonstrate that low-density targets are a promising candidate for an efficient compact proton source. This source can be optimized by choosing appropriate plasma conditions.