Advanced mechanisms for laser-driven ion acceleration

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Project description: The interaction of intense, ultra-short laser pulses with matter leads to extreme physical conditions. Matter is ionized instantaneously, and transformed into a plasma, which can support extremely large electric fields arising from local charge separation. These fields are at the basis of a number of innovative schemes for accelerating particle beams to high energies. Over the past decade, our group at QUB has been active in particular in the acceleration of protons and carbon ions [1], species of specific medical interest due to their use in advanced forms of cancer therapy. The applicative potential of these sources is also a main motivation behind the establishment of the ELIMAIA ion beamline [2] at the ELI Beamlines Institute in Prague (Cz), which is sponsoring this studentship.

The most established laser acceleration mechanism for protons, now investigated for 20+ years, is the so-called Target Normal Sheath Acceleration [1], where laser-energised electrons set-up sheath electric fields at the rear surface of laser-irradiated foils, typically having thickness of a few μm. This is a relatively simple and robust scheme, which however has limitation in terms of efficiency and energy scaling.

Efficient acceleration of Carbon ions has been demonstrated through a more advanced mechanism, Radiation Pressure Acceleration (RPA), where the accelerating field is sustained by the enormous radiation pressure associated to an ultra-intense laser pulse [1, 3-5]. The accelerating field is here generated by the local, pressure-induced displacement of electrons, within a high-density plasma layer. This scheme employs extremely thin foils, down to a few nm thickness, is experimentally demanding and has very stringent requirements on laser performance.

The aim of this project is to further advance laser-acceleration of protons and carbons towards the high energies of direct relevance to cancer therapy. The two main areas of activity will be:

1) Optimization of RPA on ultrathin foils, by careful control of the laser's temporal and spatial profile. A major factor currently limiting the efficiency of this acceleration process is the expansion of the foil during the irradiation, which causes the target to become transparent to the laser radiation as the peak plasma density decreases. Theoretical predictions indicate that transparency can be delayed by appropriate tailoring of the laser properties, which would lead to a very significant energy gain.
2) Experimental investigation of a novel acceleration concept, based on the laser-driven excitation of high amplitude surface waves along the target surfaces [6]. In this scheme, electrons accelerated by the wave along the target form an enhanced sheath at the target's edge, which accelerates efficiently ions present at the edge's surfaces. This is predicted to lead to significantly higher energy than in TNSA for the same laser parameters, as well as to enhanced proton beam properties.

These studies will be pursued employing world-leading ultrashort, Petawatt laser systems. The project is collaborative with ELI Beamlines (Cz), and will include placements in this institute while using their high-repetition HAPLS laser system and ELIMAIA target station and contributing to the facility's flagship experimental activities within the framework of the EU-funded IMPULSE project. Additional experiments will be carried out at other relevant laser facilities in UK (GEMINI, CLF-RAL) and Europe (Apollon, France). The experimental activity will be complemented and supported by numerical simulations employing Particle-in-Cell codes. The student will have the opportunity to contribute to internationally leading research activities, and will gain advanced expertise in plasma and acceleration physics, particle diagnostics, data analysis methods and computational tools.

The project is funded by ELI Beamlines for 3.5 years, and will include a salary enhancement of £2,000 per annum over the baseline student stipend. Students from UK and ROI are eligible for full funding through this studentship, as well as international students satisfying UK residency requirements.

Reading material:

1. A.Macchi, M. Borghesi, M. Passoni, *Ion acceleration by superintense laser-plasma interaction*, Rev. Mod. Phys., **85**, 751 (2013)
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3. C. Scullion *et al*, *Polarization dependence of bulk ion acceleration from ultrathin foils irradiated by high intensity, ultrashort laser pulses*, Phys. Rev. Lett., **119**, 054801 (2017)
4. A. McIlvenny *et al*, *Selective ion acceleration by intense radiation pressure*, Phys. Rev. Lett., **127**, 194801 (2021)
5. H.M.Hill, *A laser selectively kicks carbon out of a foil*, Physics Today, **75**,1,19 (2022)
6. X.F.Shen, A. Pukhov, B. Qiao, *Mono-energetic ion source via femtosecond laser interacting with a microtape,* Phys. Rev. X, **11**, 041002 (20