Optimisation of multi-petawatt laser-driven proton acceleration in the relativistic transparency regime

J. Goodman[1], M King[1,2], R Wilson[1], R J Gray[1], P McKenna[1,2]
[1] *SUPA Department of Physics, University of Strathclyde, Glasgow, U.K.*
[2] *The Cockcroft Institute, Sci-Tech Daresbury, Warrington, UK.*
jack.goodman@strath.ac.uk, paul.mckenna@strath.ac.uk

Laser-driven ion acceleration has received significant attention over the past two decades as a compact source of ultra-short, high-flux bunches of energetic (tens-of-MeV) ions with wide-ranging potential applications, such as medical oncology, industrial processing and ultrafast imaging. This acceleration is possible due to the high magnitude electric fields, of the order of MV μm^{-1}, produced in dense plasma irradiated by relativistically intense laser light.

It has been demonstrated experimentally and numerically that the use of ultrathin foils which undergo relativistic induced transparency during the interaction are a promising approach to achieve high energy laser-accelerated ions. The portion of laser light transmitted through an expanding ultrathin foil results in additional heating of the plasma electrons in the region through which it propagates, which can enhance the electric fields and thus ion energies. This forms the basis of the laser break-out afterburner [1] mechanism and the transparency-enhanced hybrid RPA–TNSA scheme [2].

Here we investigate laser-driven proton acceleration from ultrathin foil targets that undergo relativistic self-induced transparency (RSIT) and correlate the maximum proton energy and laser-to-proton energy conversion efficiency with the onset time of transparency [3] (see Figure 1). This is investigated using 2D and 3D particle-in-cell simulations to explore an intensity range from 10^{20}-10^{23} Wcm^{-2}, for both linear and circular laser polarisation. This includes evaluating the impact of the temporal contrast of the laser pulse and the influence of the high-field effect of radiation reaction at the highest intensities.

Over the full-range of parameters explored, the onset time of RSIT relative to the temporal peak of the laser pulse interacting with the target is found to be a key defining factor in both the maximum proton energies and conversion efficiency. These results will inform the design and development of future experiments and ion sources which make use of the laser-ion acceleration enhanced by RSIT.

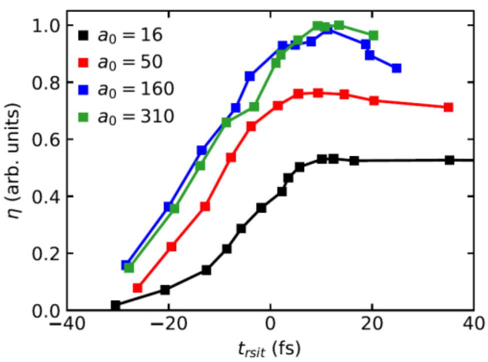

Figure 1: Normalised laser-to-proton energy conversion efficiency as a function of the onset time of relativistic transparency, for 4 example intensities.

Acknowledgments
This work was financially supported by EPSRC (grant numbers EP/R006202/1 and EP/V049232/1) and STFC (Grant Number ST/V001612/1), the Plasma Physics HEC Consortia (EP/R029148/1) and funding from Laserlab-Europe (Horizon 2020 (Grant no. 871124).

References
[1] L. Yin et al., Laser Part. Beams **24**, 291 (2006)
[2] A. Higginson A et al. Nature Commun. **9**, 724 (2018)
[3] J. Goodman et al. New J. Phys. **24**, 053016 (2022)