QUEEN'S UNIVERSITY BELFAST | SCHOOL OF MATHEMATICS AND PHYSICS

Report on thesis:

'Laser Ion Acceleration: Theory and Simulation'

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The aim of the thesis is the exploration of laser-driven proton acceleration via target normal sheath acceleration from novel shaped targets. The goal of the study is the reduction of proton beam divergence to facilitate both capture and transport by conventional beam optics and use for a variety of applications. The primarily focus of the author is on 2D and 3D particle-in-cell (PIC) simulations using the code EPOCH. The simulations compare flat foils with novel targets including channel foil, curved foil and tapered foil. The thesis characterises all aspects of the acceleration and in particular correlates the magnetic field structure at the target rear surface with multipole magnets. This work complements experimental and computational studies over recent years demonstrating improved collimation of proton beams from hemispheric targets, wedged targets, helical coil targets and others.

The thesis is organised as follows:

Chapter 1 is devoted to a comprehensive summary of the theory of laser-driven ion acceleration mechanisms including target normal sheath acceleration (particularly relevant to the bulk of the thesis), radiation pressure acceleration, relativistic transparency and associated break-out afterburner as well as magnetic vortex acceleration. In addition, over-critical electron heating mechanisms and their relative importance for different incident laser intensities and polarisations are clearly explained.

Chapter 2 details additional factors with a strong influence on practical laser-driven ion acceleration. These include the influence of laser contrast through the generation of a preplasma scale length and disruption of the target rear surface, relativistic self-focusing and the generation of magnetic fields.

Within this chapter the author also provides a background on multipolar magnets, associated terminology and their utility as beam optics.

Chapter 3 includes an excellent introduction to plasma modelling. The primary focus is on particle-in-cell codes as relevant to the bulk of the work but hydrocodes and statistical kinetic codes are also introduced. In particular, the explanation of the required CPUs and temporal and resolution limits is very nicely summarised.

Chapter 4 contains the bulk of the author's own work. This includes the simulation in 2D and 3D of a set of novel targets as outlined previously. Extensive analysis of various aspects of the interaction and ultimate proton beam quality are presented. These include; comparison of 2D with 3D, of transversely prolong targets and mass limited targets, varying incident laser polarisation, as well as of the influence of laser preplasma. The chapter assesses the resultant beam quality in terms of divergence and spatial profile, maximum energy and charge in energy slices of the beam, as well as phase space.

Finally Chapter 5 presents various applications of proton beams, such as proton therapy and artefact studies

using PIXE and DPAA, together with the specific proton beam parameters required for these applications and the advantages of using laser-driven protons as opposed to conventionally accelerated proton beams. In addition to this, the chapter includes a summary of the thesis work.

The thesis is detailed showing a both deep and broad understanding of the relevant topics. It contains substantial detailed analysis and simulations performed by the candidate and discussed in the framework of other recent work within the field and also within the context of conventional beam optics.

From the written thesis, the candidate deserves the opportunity to defend their work. Particular questions which should be clarified/comments include:

- In Chapter 1, given the lengthy discussions of proton beam spatial profile in Chapter 4, it would be useful to include some examples and expanded discussion on the typical proton beam profile observed in TNSA experiments. The introduction to the efficiency of radiation pressure acceleration and break out afterburner could be clarified although these mechanisms are not crucial to the targets discussed.

- In Chapter 2, the meaning of figure 2.1 is not clear. This should be clarified in the caption. In addition on p.50 the discussion of generation and measurement of magnetic fields in laser-plasma interactions should include measurement using proton radiography (Sarri et al., PRL ,109, 205001 (2012))) and electron radiography (Schumaker et al., PRL, 110, 015-003 (2013)) for completeness. Finally, at multiple points through chapter 4, the authors mention that the magnetic field aspect ratio of the channel is insufficient for the fields to fully evolve. This concept is introduced in this chapter (2) but given it's importance to the subsequent discussion, the explanation should be expanded.

- In Chapter 3, the overview of kinetic and hydrocodes is very useful, however, in the description of kinetic codes the author moves back and forwards between the statistical and macroparticle based method and it is not always entirely clear which is being discussed. This should be adjusted slightly to improve clarity. Also on p66, I believe there is a typo in the sentence 'combine PM and PM' which should be 'combine PM and PP'.

- In Chapter 4, it is mentioned at several points that for the channel target quadrupole and octapole fields exist along the channel and evolve in time. These are presented at multiple points for fixed time but it is not totally clear how they evolve. The inclusion of a plot showing the field cross-section for several x-sections and those same planes for several times would be very useful to the overall understanding.

- Also within Chapter 4, figure 4.9 follows a test particle along the laser axis and highlights regions of focusing and defocusing field. As this particle is propagating along the axis, can the authors clarify what is meant by a focusing and defocusing in this context?

- In Chapter 5, while the description of applications of laser-plasma proton beams is very important it may be better placed in the short introductory chapter, that sets the scene for the research. This would also place the studies into context so that the reader can appreciate their application to broader research and the societal impace more completely from the start. This would then leave chapter 5 purely as a conclusion and discussion of future work.

With kind regards,

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