John Adams Institute for Accelerator Science

Imperial College London

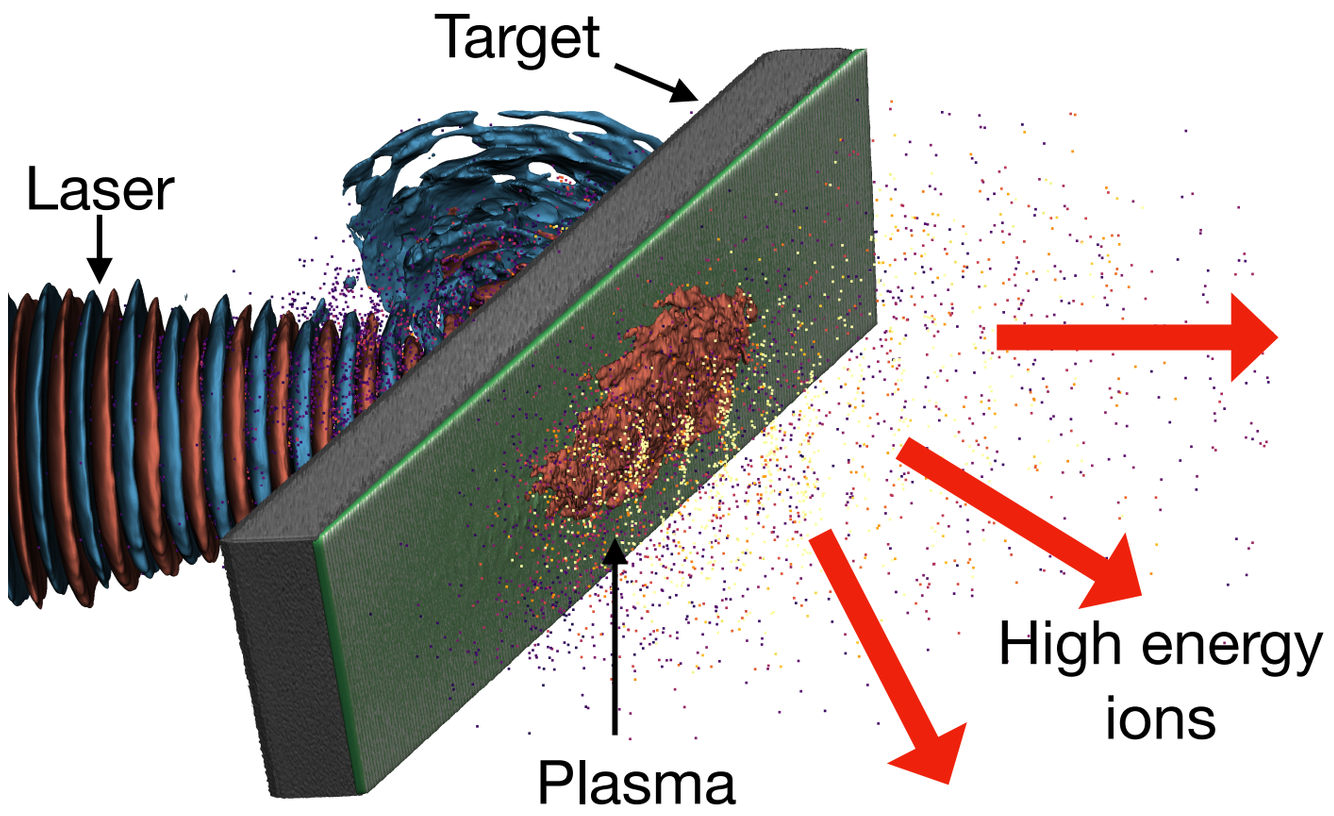
LhARA Laser-hybrid Accelerator for Radiobiological Applications

LhARA Laser-Driven Proton & Ion Source WP2

Update on recent progress

30th January 2024

WP2 objectives



Experimental R&D:

- ➡ ‘Full scale’ LhARA specification testing on SCAPA laser, Strathclyde
- ➡ LhARA focused diagnostic and targetry development
- ➡ High repetition rate, automation and longevity studies on Zhi laser, Imperial

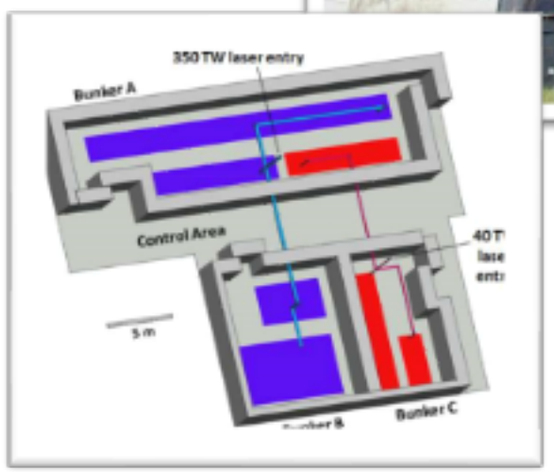
Numerical modelling:

- ➡ State-of-the-art high fidelity 3D simulations of the ion source

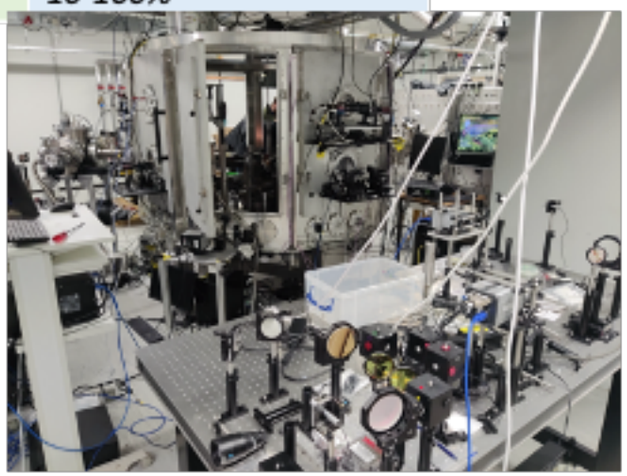
Experimental R&D at SCAPA

SCAPA: Scottish Centre for the Application of Plasma-based Accelerators

Parameters	
Peak Power	*≥350 TW*
FWHM pulse duration	*≤25 fs*
Energy per pulse (on target)	*≥ 6.5 J*
Pulse repetition rate	*Up to 5 Hz*
Temporal intensity contrast	*10^{10}:1 @ 100 ps* *10^{8}:1 @ 30 ps* *10^{4}:1 @ 2 ps* *ASE contrast 10^{10}:1*
Central wavelength	*800 nm*
Beam quality Strehl ratio	*≥0.85*
	10-100%



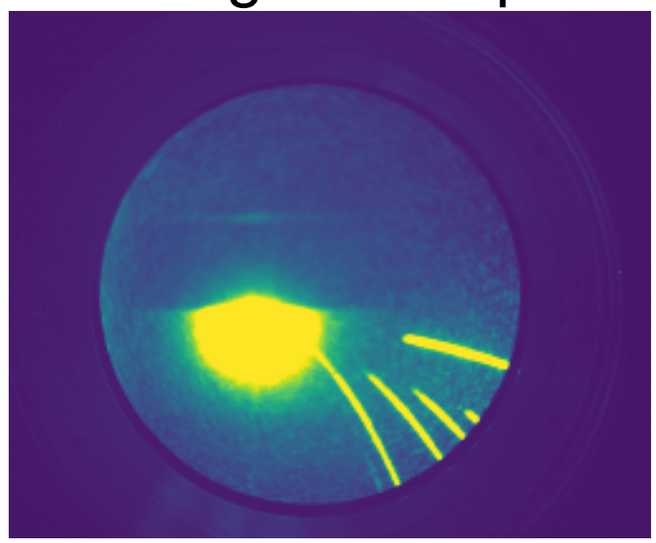
Laser-solid interaction beamline B1 in Bunker B

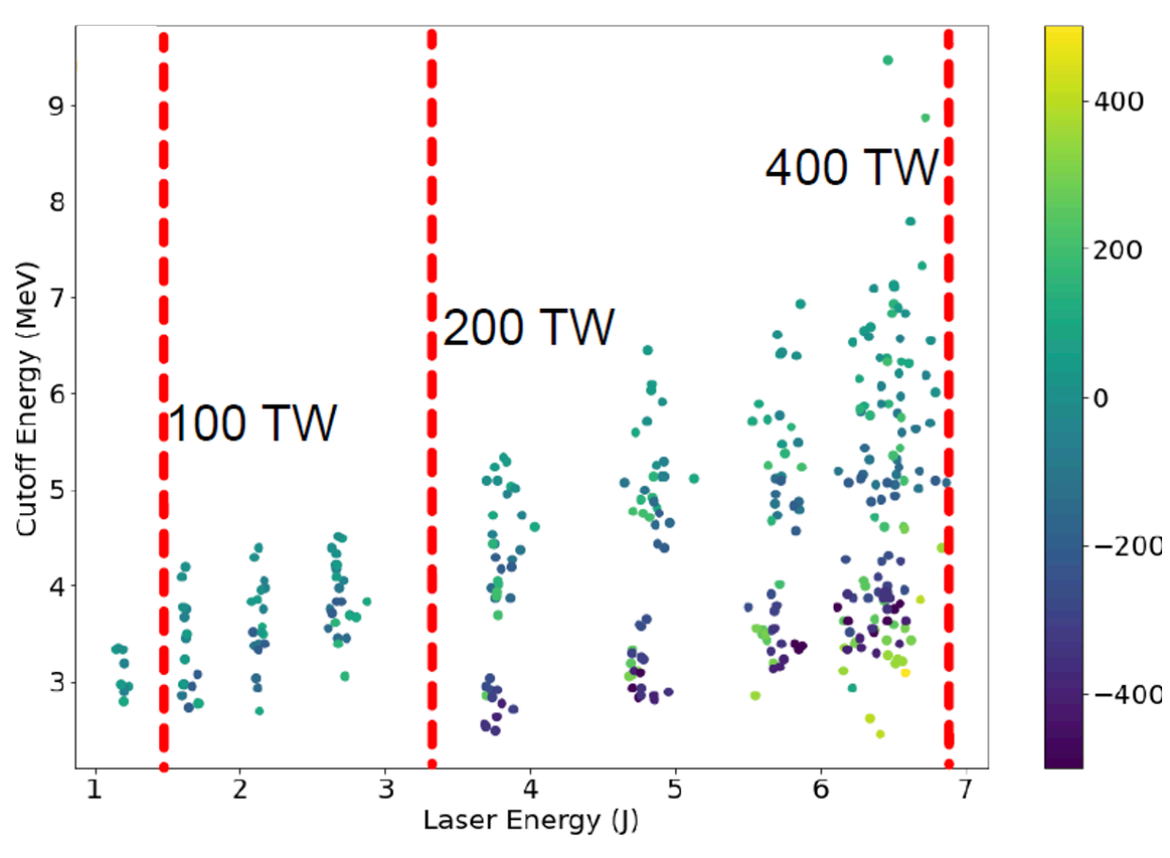


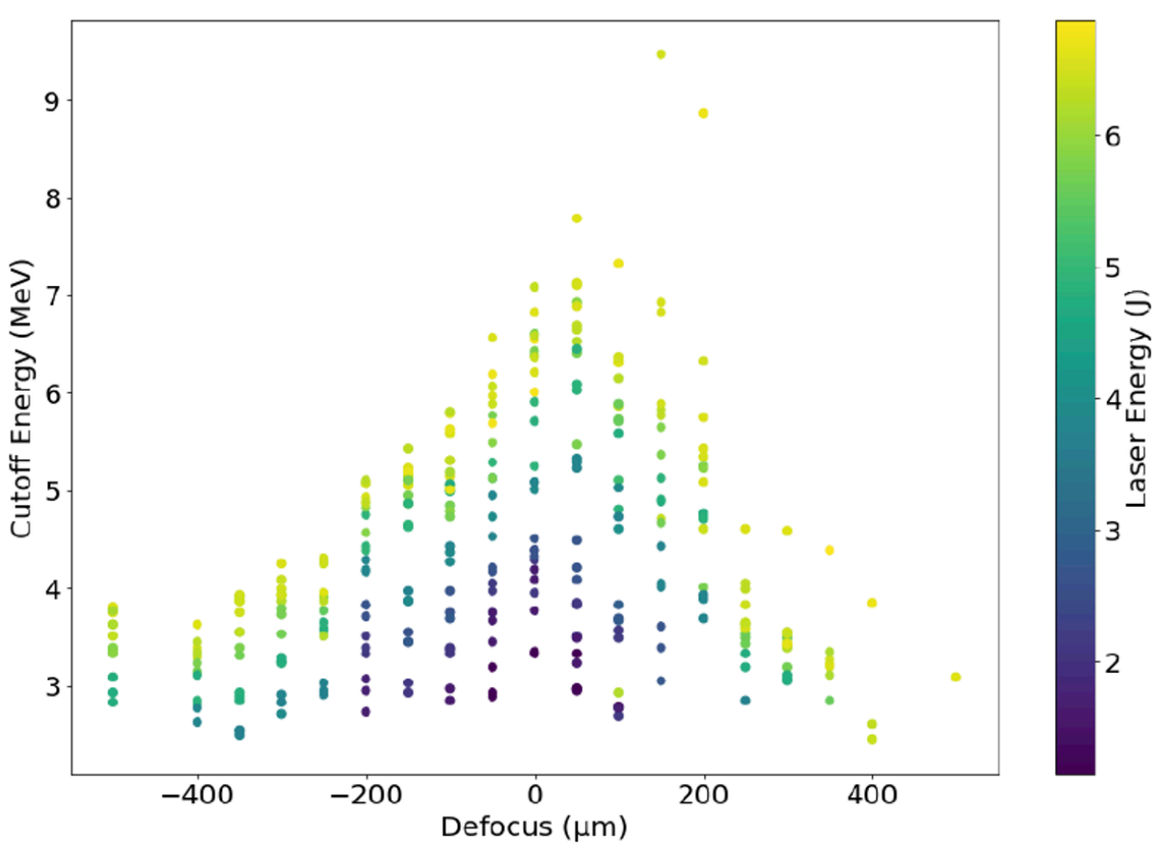
Experimental R&D at SCAPA

- First full LhARA experiment at SCAPA in July 2023 - 2000 shots, including 1 Hz operation demonstration
- Demonstrated strong sensitivity of proton energies to laser energy and focus
- Maximum energy limited by relatively thick targets and lack of density profile optimisation

Example TPS image, for extracting beam spectra







Experimental R&D at SCAPA

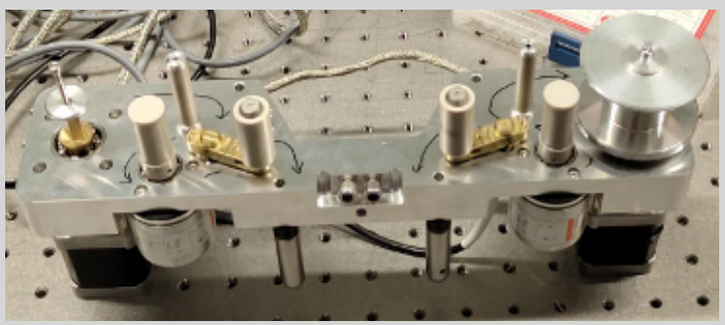
Next run in March (delayed from January)

Many improvements to the system:

Targetry

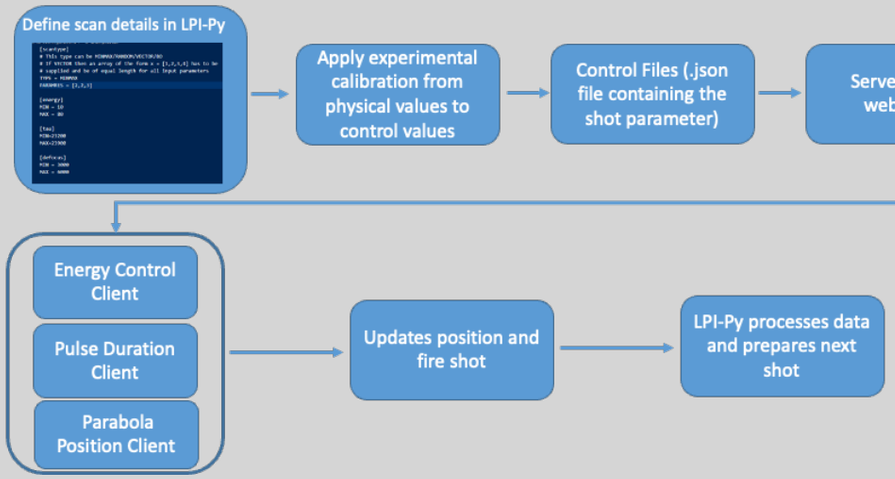
Higher energy protons by:

- ➡ Shooting thinner tape targets
- ➡ Easier target alignment
- ➡ Optimising front surface density profile using “Pre-



Experimental automation

LPI-PY: Automated Control System

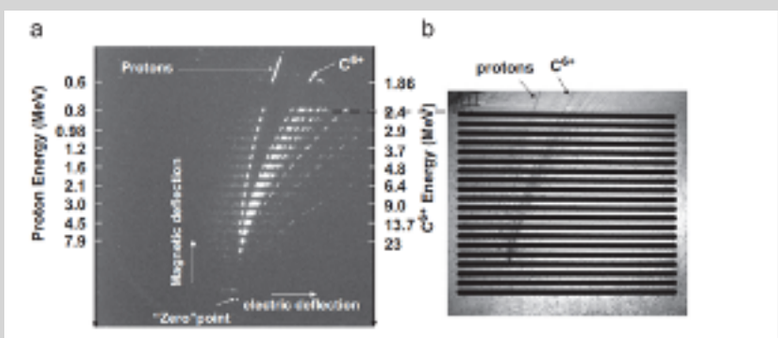


Improved diagnostics

Optimised Thomson Parabola for ion spectra

Calibration of spectrometer

Optical probing of laser generated plasma

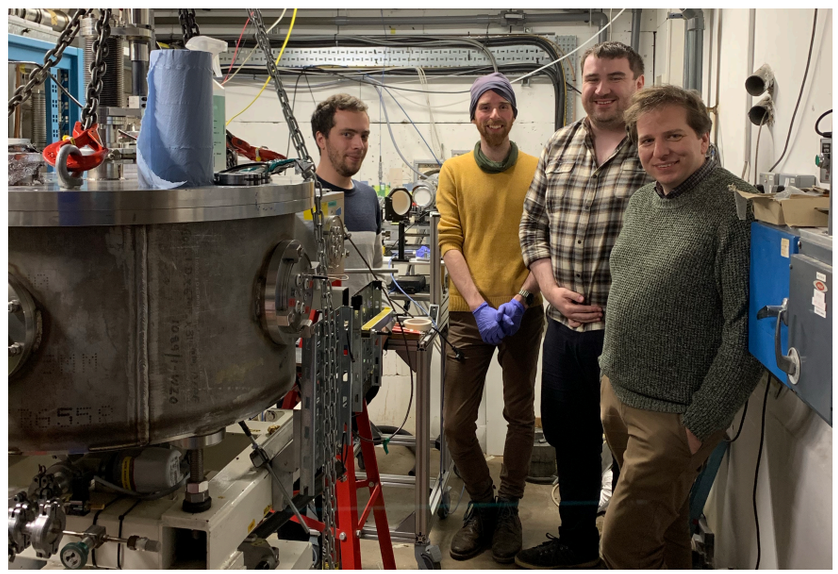


Experimental R&D of diagnostics

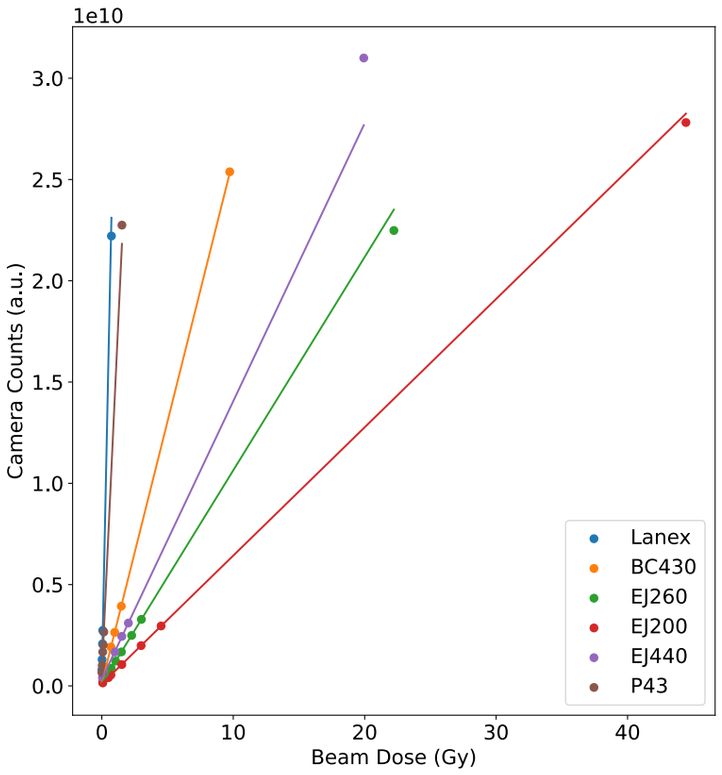
- Scintillators: key detector for high repetition operation
- Our sources give high noise background - electrons, x-rays, EMP - scintillator choice important!

  ➡ <u>Dedicated scintillator calibration experiment at MC40 Beamline at Birmingham</u>

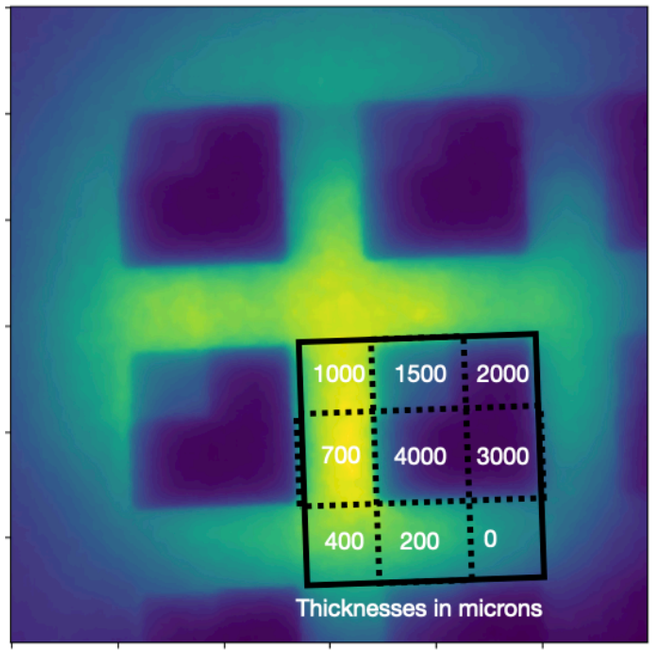
Experimental team (with some missing) - from QUB, CLF, Strathclyde and Imperial



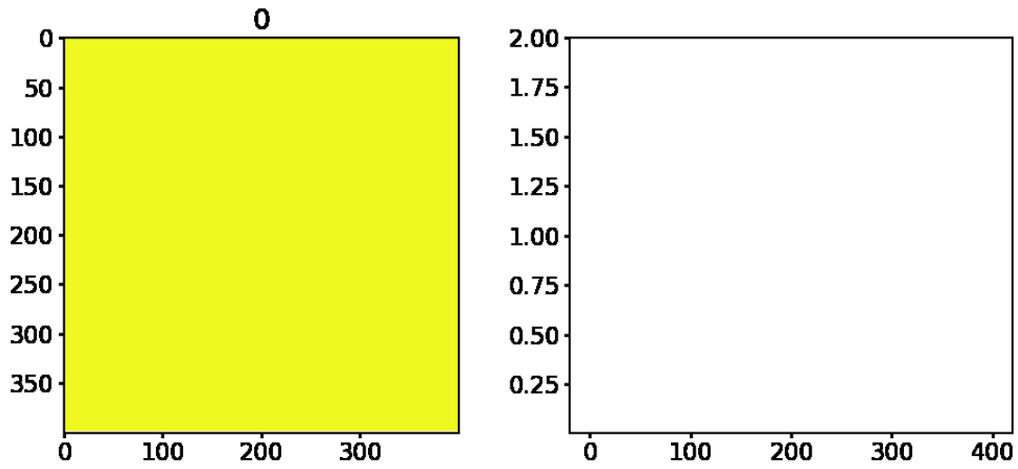
Absolute calibration and dose linearity scan



Energy dependent emission scan



Afterglow studies

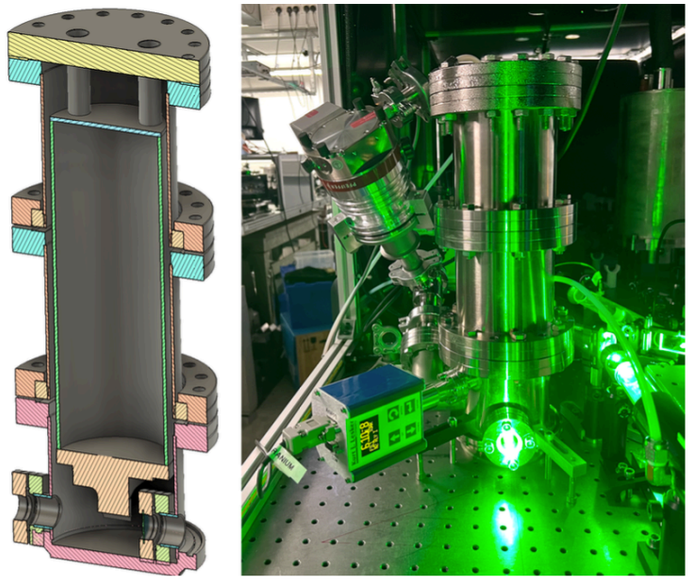


Experimental R&D at ICL - Zhi laser

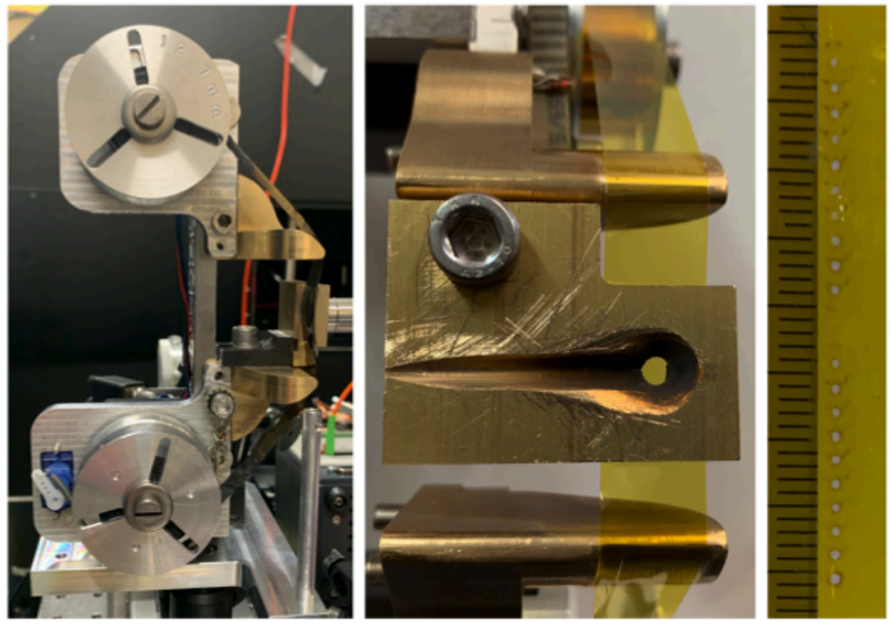
O. Ettlinger, N. Xu, Z. Najmudin



- ➡ 90 mJ of laser energy, 30 fs pulse width at 100 Hz
- ➡ Predicted maximum proton energies ~ few MeV
- ➡ Semi-continuous access allows long term R&D into technical issues in stabilisation, debris, targetry, etc



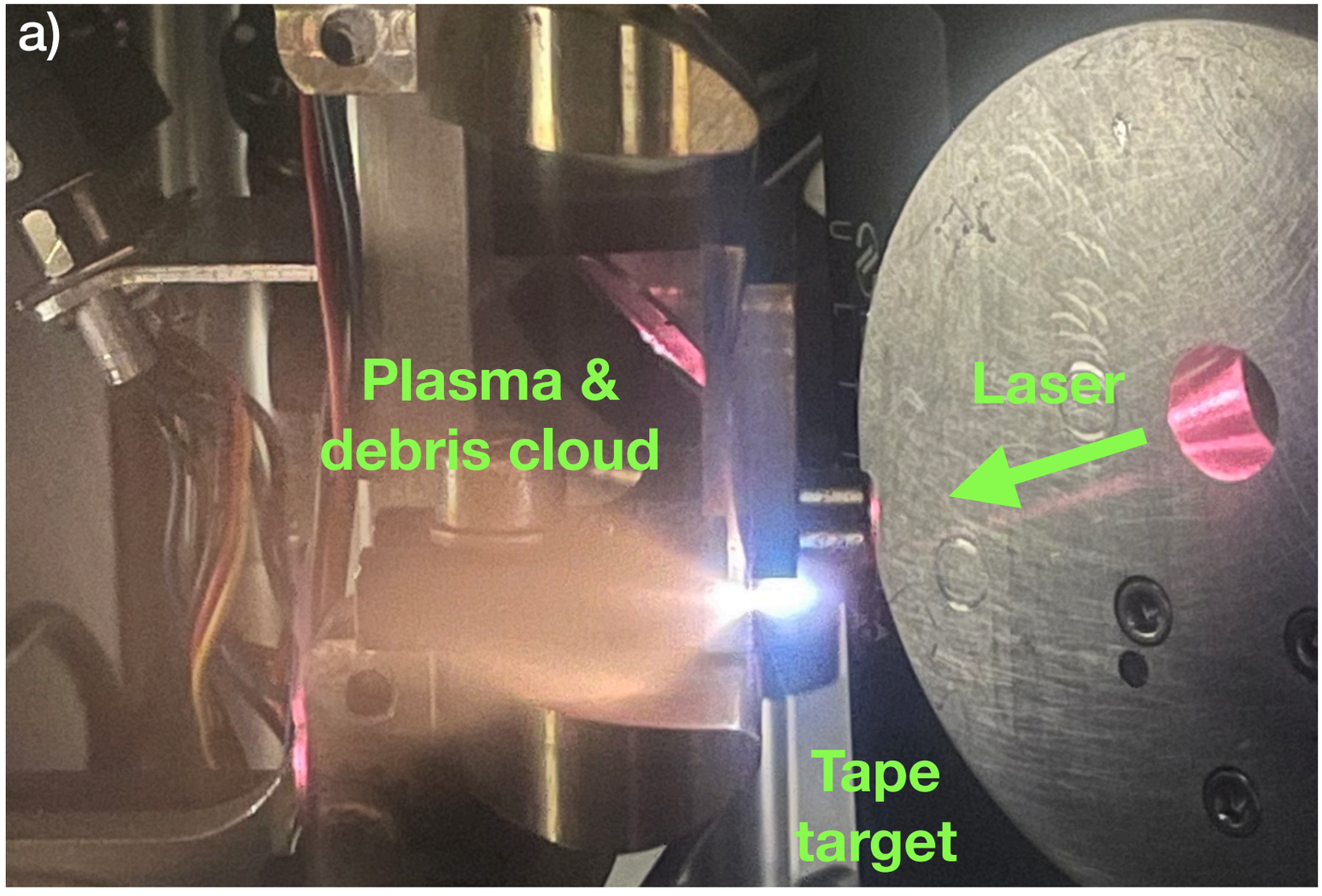
Cryogenic regenerative amplifier and 4-pass amplifier to mitigate thermal lensing



High stability homemade tape target for 100 Hz operation

Xu et al., HPLSE 11, e43 (2023)

Experimental R&D at ICL - Initial results



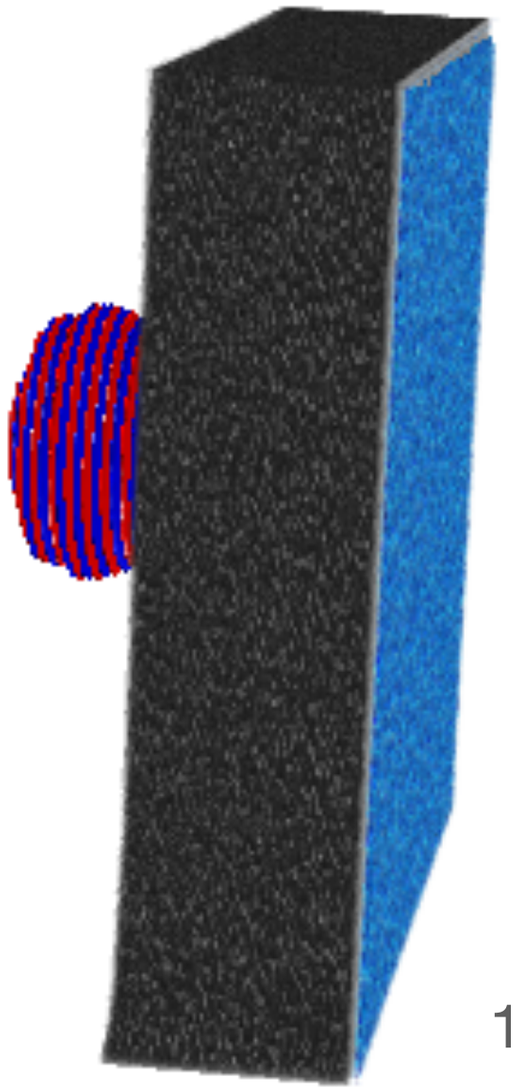
- Currently experiments run at 5 mJ level (without final amplifier)
- Continuous operation at 100 Hz for ~10 minutes
- Plasma formation, x-ray generation (and debris!) observed
- From next month, experiments begin at 100 mJ level - should start to see ions

Numerical R&D - progress on simulations

Titus Dascalu @ Lancaster

Parametric optimisation of the laser ion source continues:

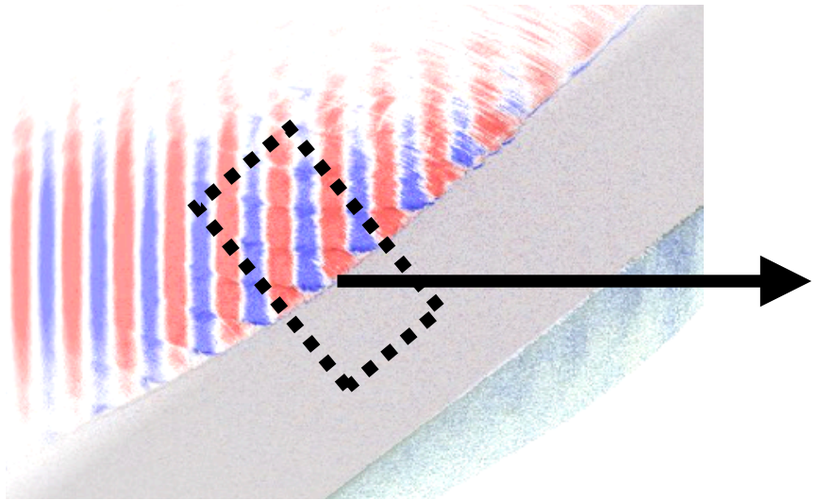
- Realistic two-stage simulation using accurate “pre plasma” density profile
- Variation of laser angle-of-incidence, laser spot size, and hydrogen layer thickness

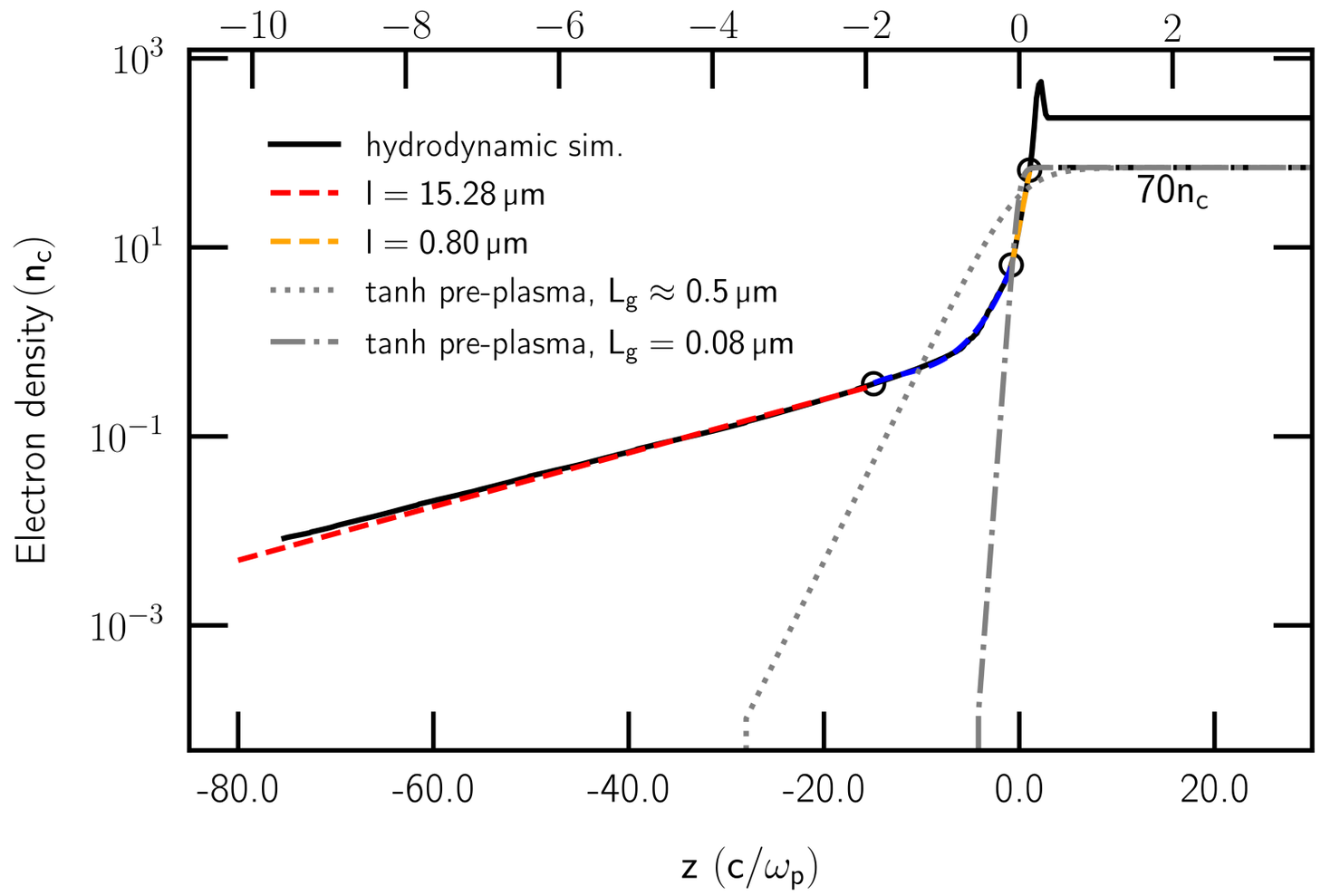


Successful application for more computation time on ARCHER2

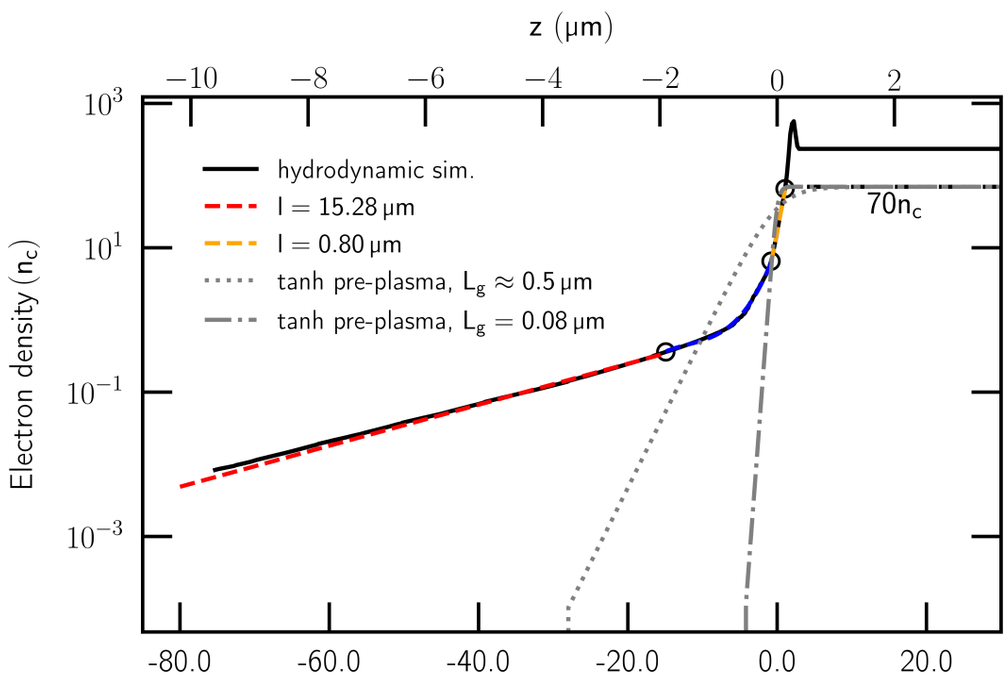
Simulations of laser prepulse

- Laser “prepulse” affects density profile that the intense part of the pulse sees, dramatically changing the laser plasma interaction
- We model this using the ‘FLASH’ code, using prepulse measurements from SCAPA
- Density profile is then used to initialise PIC simulations

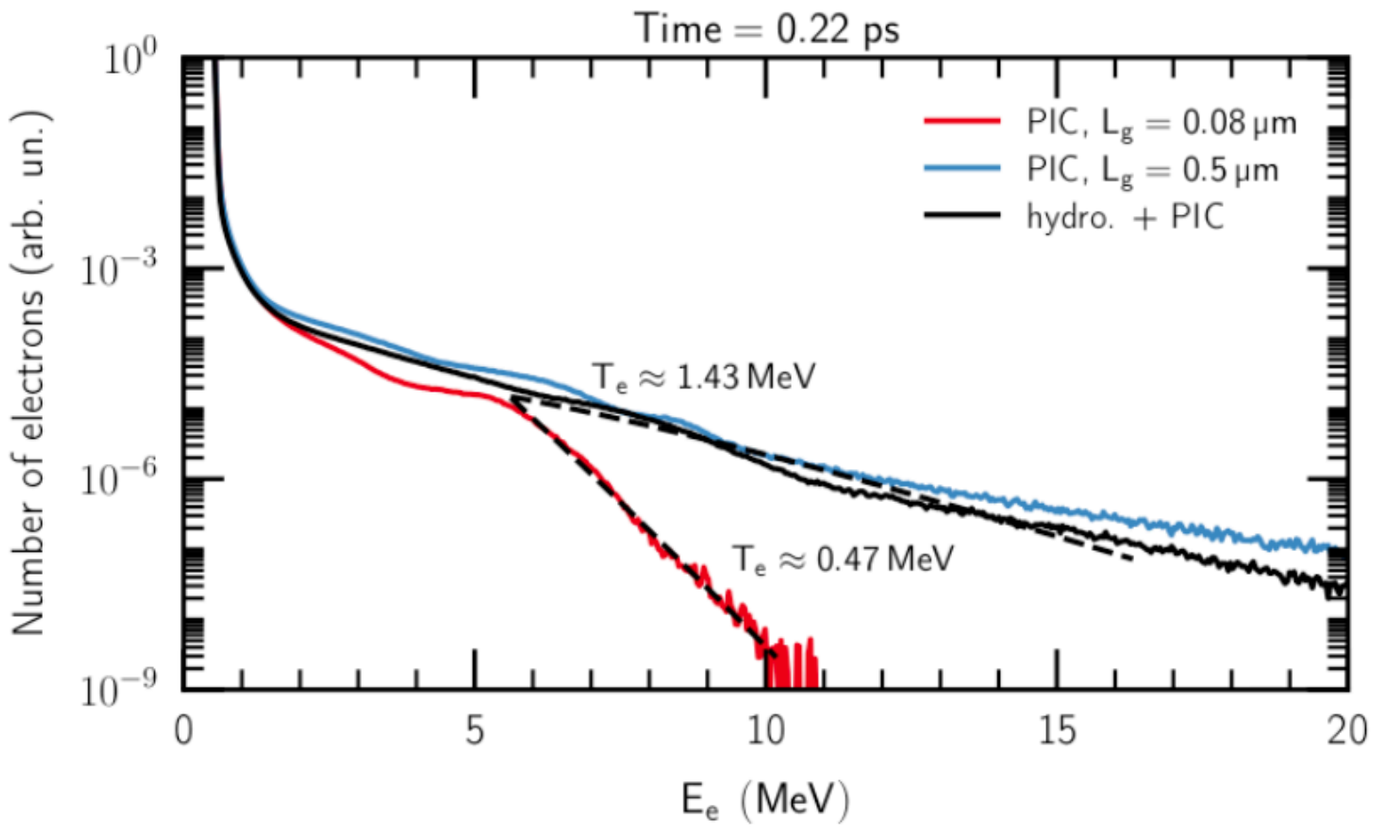


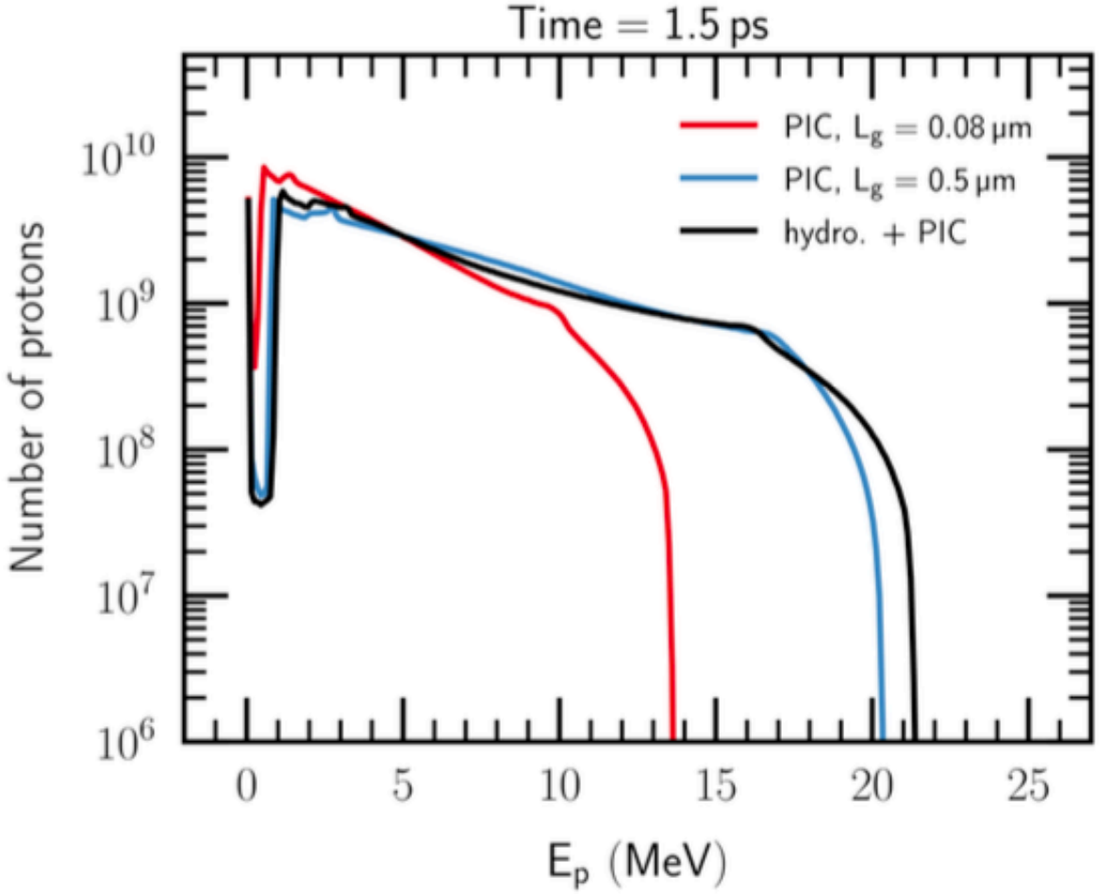


3D PIC using real laser prepulse



- Realistic profile -> good coupling into electrons, and therefore ions
- Questions to look at:
  - Optimisation by varying e.g. laser prepulse
  - Role of different scale lengths

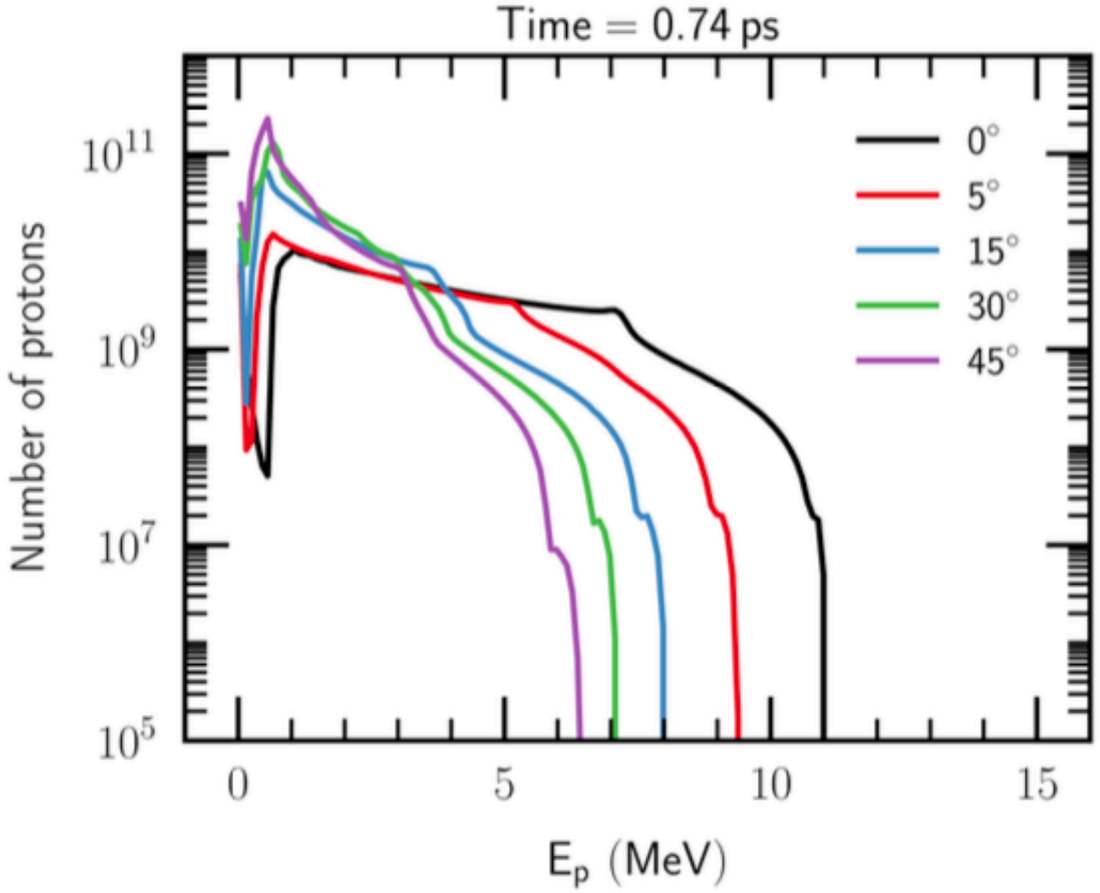




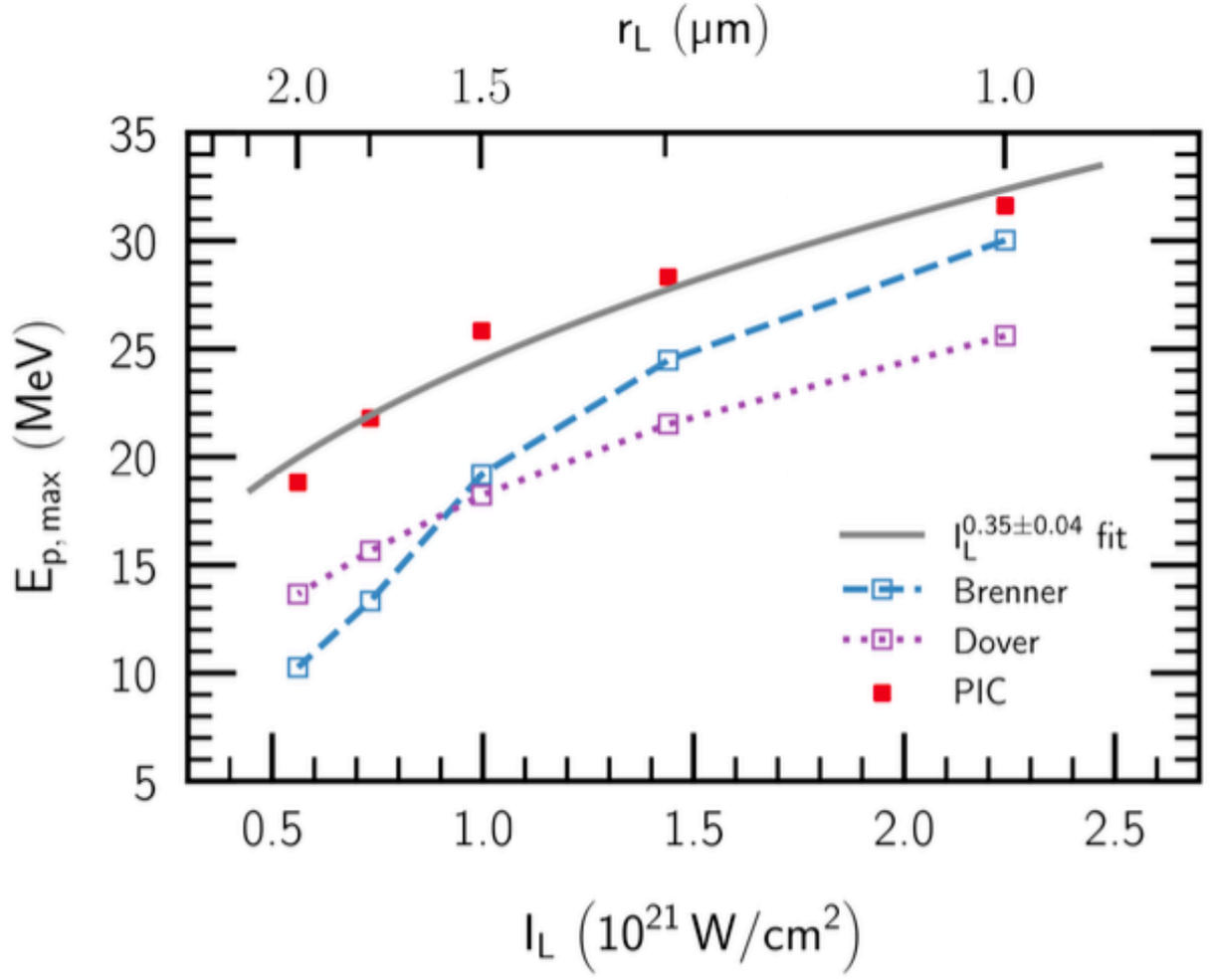
Parametric optimisation in 3D PIC

Can use 3D PIC to predict impact of parameters difficult to change in the experiment:

Vary angle of incidence of laser



Vary f-number of focusing optic



Summary

- ➡ Analysis of first SCAPA run underway; 2nd run delayed until March due to laser issues

- ➡ Characterising online detectors for LhARA experiments and optimising scintillator choice using MC40

- ➡ Ion source experiments at Imperial delayed but will be ramped up to full energy in the next month

- ➡ Numerical simulation programme is back underway and studies to define the source requirements continue