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LhARA Collaboration Meeting #5

WP2 Source Session

WP2 Overview

26th April 2024

Dr. Ross Gray
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Session Overview

9.30 – Ross Gray: Overview and Update on WP2

9.45 – Titus Dascalu: Review of Progress on PIC simulations for WP2 (Remote)

10.00 – Robbie Wilson: Update on SCAPA Development and Experiments

10.15 – Matt Alderton: Update on Ion Diagnostic Calibrations (Remote)

WP2 Team

University of Strathclyde

R. Wilson, T. Frazer, E. Dolier, C. McQueen, B. Torrance, M. Alderton R. Nayli and P.McKenna

Imperial College

O. Ettlinger, G. Casati and N.P. Dover

Queens University Belfast

P. Parsons and C. Palmer

SCAPA, University of Strathclyde

M. Wiggins, E. Brunetti, G. Manahan, W. Li

Central Laser Facility

J. Green, C. Armstrong, C. Spindloe, W. Robins, S. Astbury

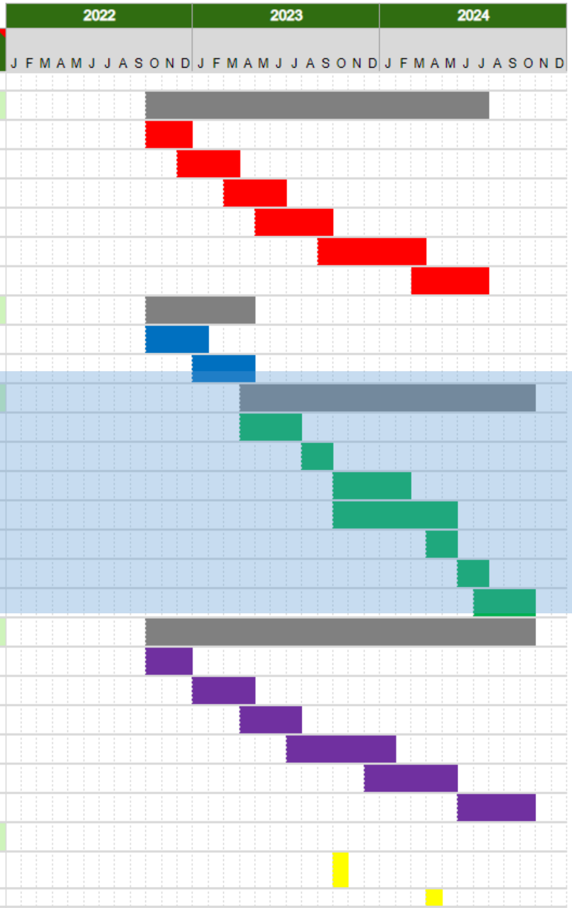
Lancaster University

T. Dascalu

WP2 project plan…

LhARA WP2 Gantt Chart

TASK DESCRIPTION	START	END	TYPE
O1 - Baseline Simulations (Lancaster)	01/10/2022	01/07/2024	
Convergence Testing and Benchmarking	01/10/2022	01/12/2022	R
Hydrodynamic modelling of laser contrast	01/12/2022	01/03/2023	R
2D PIC modelling of TNSA for proton acceleration on SCAPA	01/03/2023	01/06/2023	R
3D 'full scale' simulations for proton acceleration on SCAPA	01/05/2023	01/09/2023	R
2D PIC modelling of TNSA for heavy ion acceleration on SCAPA	01/09/2023	01/03/2024	R
3D 'full scale' simulations for heavy ion acceleration on SCAPA	01/03/2024	01/07/2024	R
O2 - Diagnostic Package (Strath/IC)	01/10/2022	01/04/2023	
Concept design for diagnostic platform	01/10/2022	01/01/2023	B
Testing preliminary ion diagnostics	01/01/2023	01/04/2023	B
O3 - Baseline SCAPA experiments (Strath)	01/04/2023	01/10/2024	
Experiment Planning, Design and Preparation	01/04/2023	01/07/2023	G
SCAPA ion source commissioning experiment	01/08/2023	01/09/2023	G
Data Processing and Analysis	01/10/2023	01/02/2024	G
Simulation Benchmarking and Iteration	01/10/2023	01/05/2024	G
Experiment Planning, Design and Preparation	01/04/2024	01/05/2024	G
SCAPA experiment on parametric optimisation of source	01/06/2024	01/07/2024	G
Data Processing and Analysis	01/07/2024	01/10/2024	G
O4 - Advanced targetry, debris and stablisation studies (IC/Lanc)	01/10/2022	01/10/2024	
Experiment Planning, Design and Preparation	01/10/2022	01/12/2022	P
Initial Baseline Experiment at IC for source characterisation and stability	01/01/2023	01/04/2023	P
Data Processing and Analysis	01/04/2023	01/07/2023	P
Experiment Planning, Design and Preparation	01/07/2023	01/01/2024	P
Base line experiment for debris and contaminant removal studies	01/12/2023	01/05/2024	P
Data Processing and Analysis	01/06/2024	01/10/2024	P
WP2 milestones			
M2.1: Prediction of optimised proton source for 100+ TW laser systems based on hydrodynamic and kinetic simulations	01/10/2023	01/10/2023	Y
M2.2: First SCAPA ion source simulations and experiment completed	01/04/2024	01/04/2024	Y



- Deliverables for the first two years are focused on early experiments and source benchmarking in simulations, as well as initial technology development in diagnostics and targetry.
- For the initial experiments we would ideally like to perform detailed, statistically significant parameter scans to establish and optimise the source performance.

Implementing the project plan…

Experimental R&D:

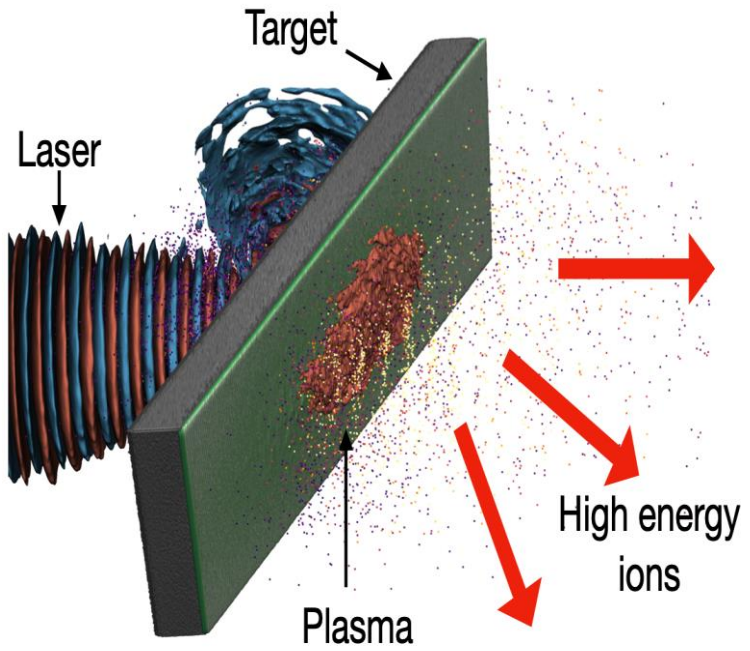
- ‘Full scale’ LhARA specification testing on SCAPA laser, Strathclyde
- Application focused diagnostic and targetry development
- High repetition rate, automation and longevity studies on Zhi laser, Imperial

Numerical modelling:

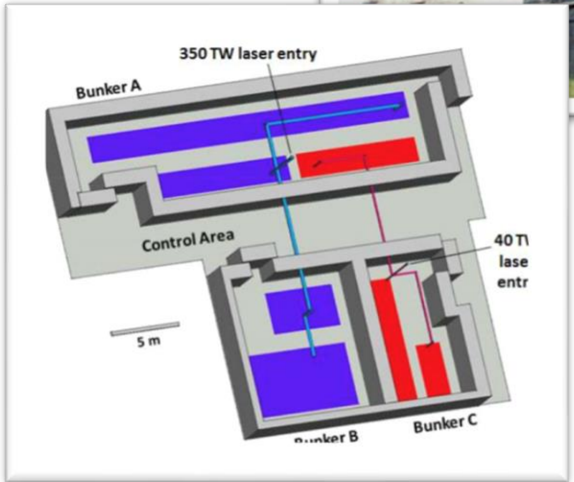
- State-of-the-art high fidelity 3D simulations of the ion source
- Parametric optimisation to support experimental studies

Planned outputs from WP2

- High energy (e.g. ~15 MeV p+, 4 MeV/u C6+) from source
- Operations at up to 1 Hz for extended periods (extending to 5 and 10 Hz)
- Aiming to deliver 10^9 protons or 10^8 carbon ions per shot, eventually other ions
- Initially tape targets, but developing other options, e.g. water jet

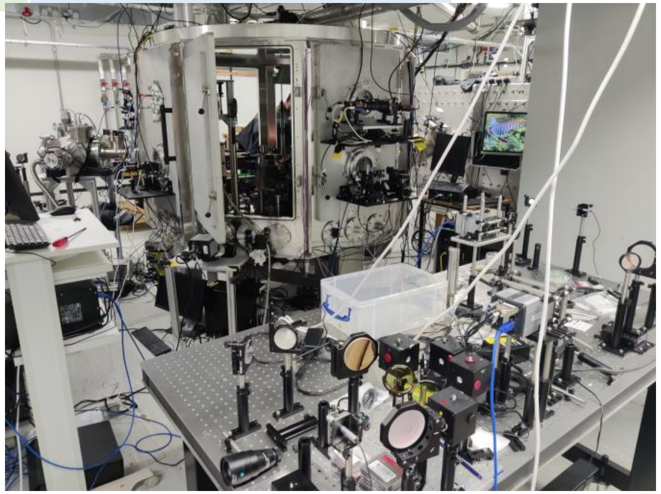


SCAPA: Scottish Centre for the Application of Plasma-based Accelerators



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.

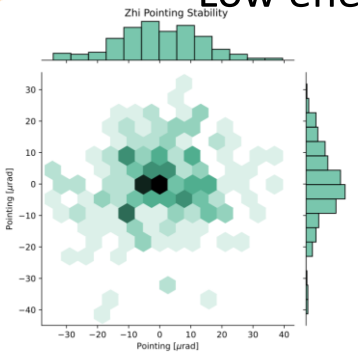


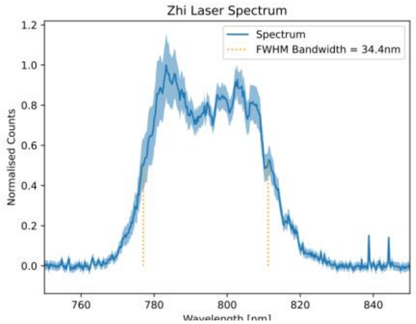
R&D with Zhi

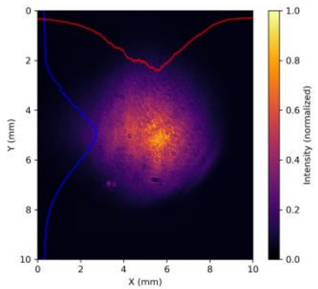
100Hz Ti:Sapphire Laser System:

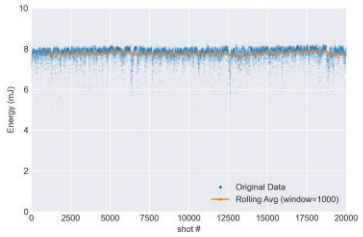
- mJ level operation for “table top” experiments at % level stability
- 100mJ level output for higher power electron and ion acceleration experiments
- current design offers scalability to run at current levels to multi-kHz repetition rates, or Joule level Ti:Sapphire energies at 100Hz.

Low energy output



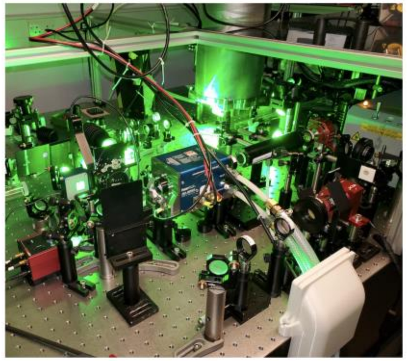


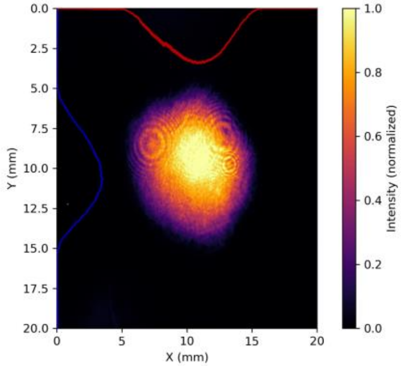




High energy output

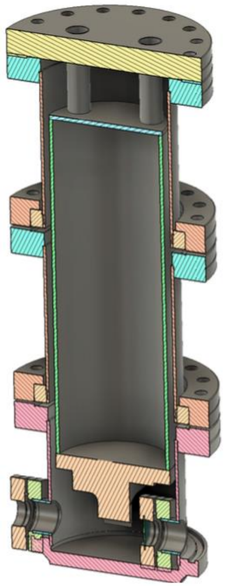
65mJ output already demonstrated - new amplifier will allow >100mJ

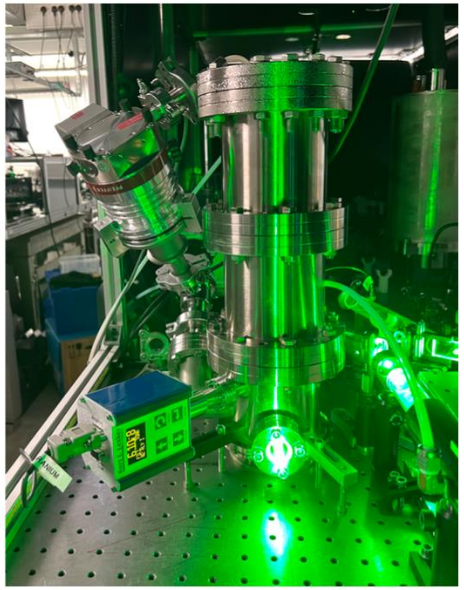




R&D with Zhi

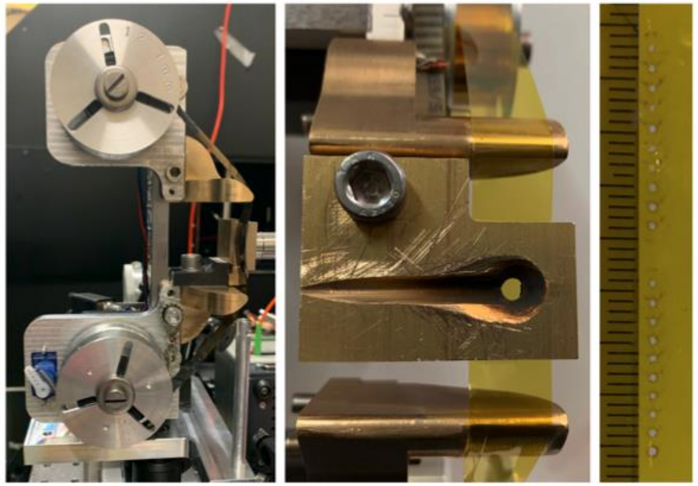
Cryogenic regenerative amplifier and 4-pass amplifier to mitigate thermal lensing



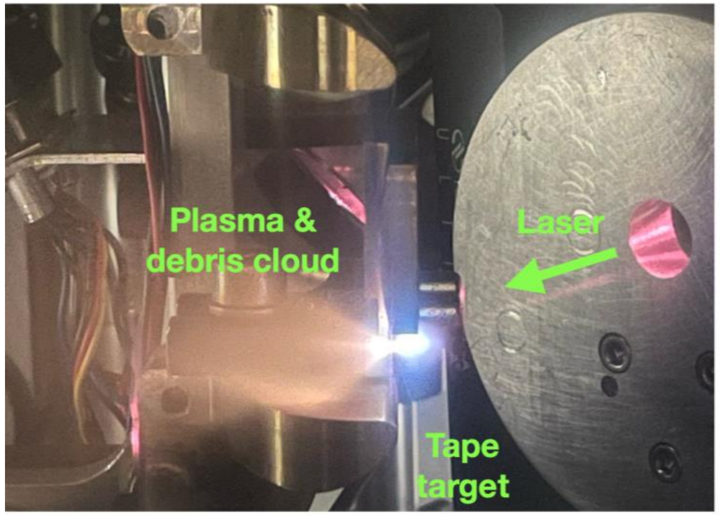


High stability homemade tape target for 100 Hz operation

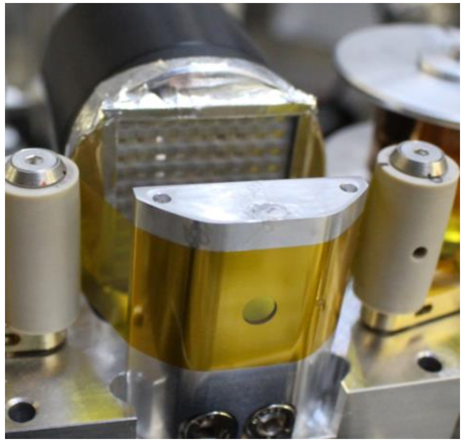
Xu et al., HPLSE 11, e43 (2023)



Ion source and diagnostics are undergoing testing to run at 10+ Hz

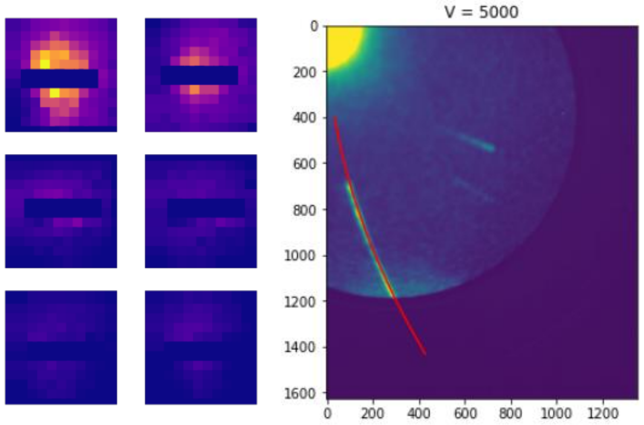


Delivering on the WP2 Objectives…



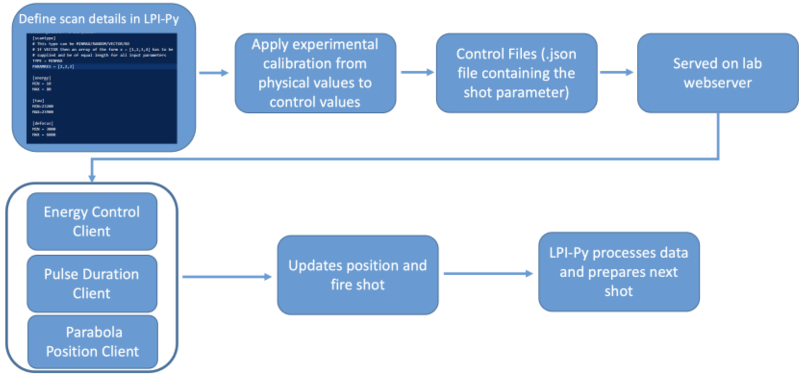
High Rep & Targets

- High-repetition tape rate target now updated and operational
- 3x Experimental beamtimes (1 LhARA funded and 2 as part of internal commissioning) all exceeding 1000 Shots
- Comfortably operating at 0.1 Hz and have operated at 1 Hz for short periods. Key issues around 'pellicles' at rep rate have now been resolved.



Diagnostics

- PROBIES: High-repetition rate proton beam profiler and spectrometer now tested with an updated design
- New high repetition rate TP code has been tested and validated on calibration shots (1Hz analysis)
- Work ongoing at Birmingham and SCAPA to aid in diagnostic development and absolute calibrations



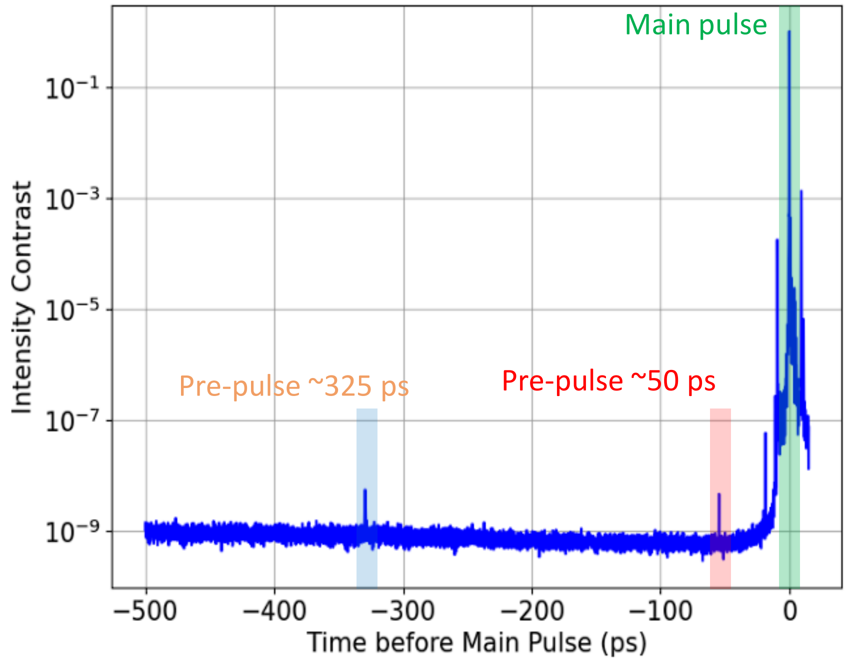
Automation and ML

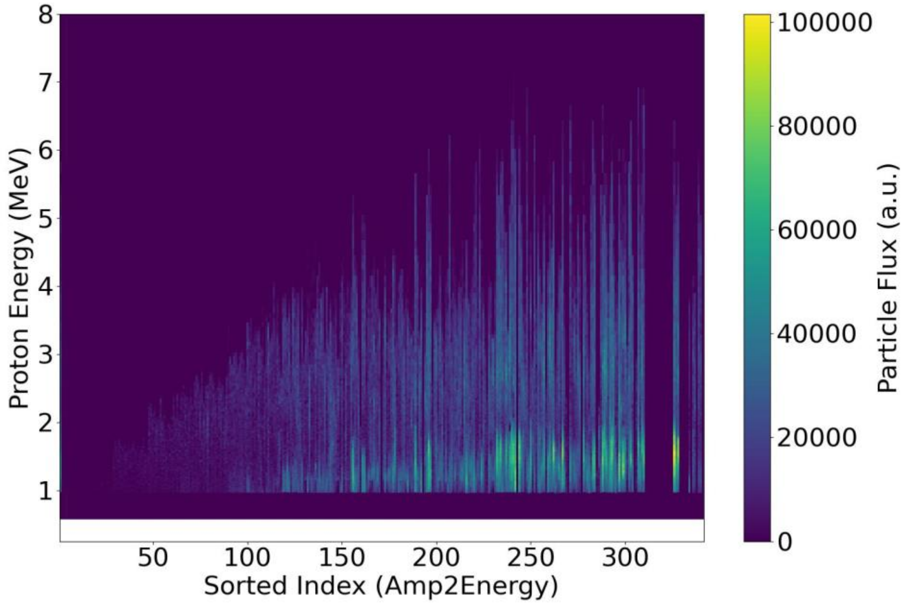
- Substantial updates to our LPI-Py library enabling automated data scans
- Also updates to enable Bayesian optimisation/ML-driven experimental runs
- New and ongoing work to update our drive system to streamline these controls
- Now running fully 3D EPOCH+FLASH simulations

Next steps….Further optimisation of TNSA ion source on SCAPA

- Robbie will report on the details of SCAPA development but we have identified an issue which is currently limiting our maximum proton energy to around 7 MeV.

- This is likely to be related to the laser ‘temporal intensity contrast’ which results in changes to the front surface plasma profile and significantly changes the source performance

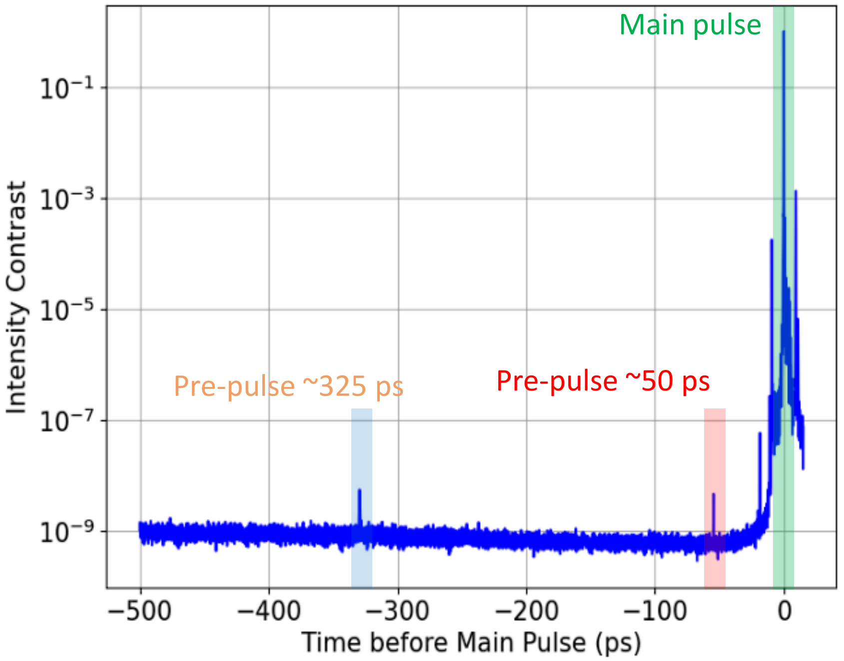


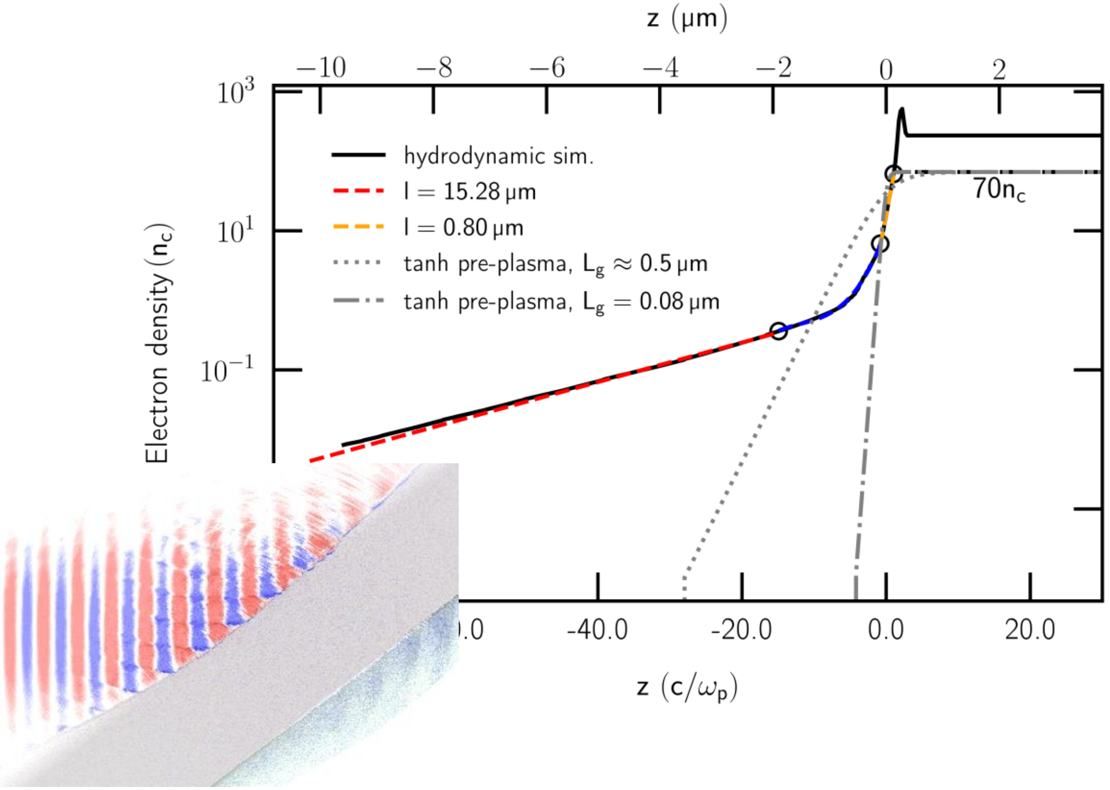


Next steps….Further optimisation of TNSA ion source on SCAPA

- We will need to bring our double plasma mirror system online in the short term while also investigating optics which are generating prepulses in the system.

- Simulations by Titus will also help us understand the role of these prepulses and the contrast overall on the optimisation of the ion source.





Summary

- At the 18 month mark we have made significant progress towards key objectives

- The ‘hard part’ is almost complete. We have demonstrated high repetition rate operations, automated control and have developed suitable online diagnostics

- Work at Imperial will identify new directions in terms of long-term operations and the simulation programme will support further optimisation of the source

- Prepulses identified via contrast measurements on SCAPA are likely to be the main culprit preventing higher proton energies but we have a plan…

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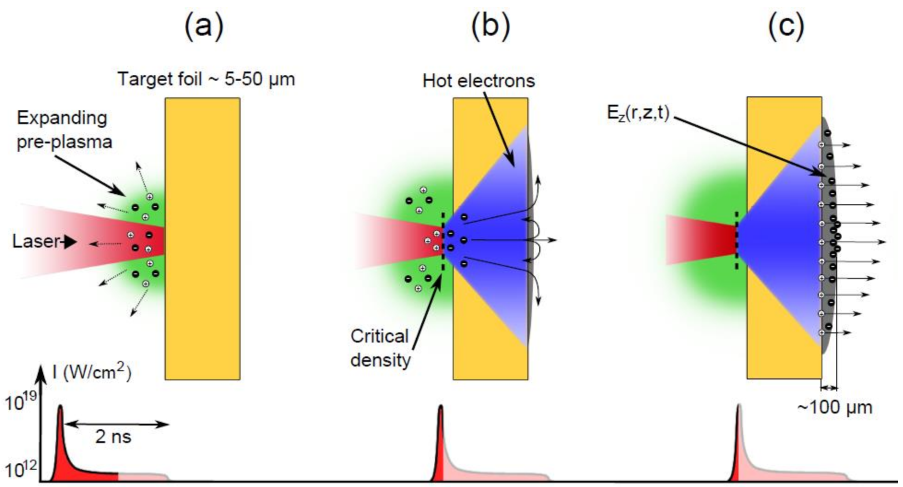
Considerations for a laser driven proton source from Target Normal Sheath Acceleration mechanism (TNSA)



- **Fast electron temperature** and **fast electron density and total number** at the rear surface drive proton **spectral** characteristics

- The fast electron properties are sensitive to a wide range of input parameters:

Laser:
- Intensity
- Energy
- Focal spot size
- Laser intensity contrast
- Polarisation
- …

Plasma:
- Energy conversion efficiency
- Fast electron divergence angle
- Z (scattering, resistivity)
- Preplasma scale length
- …

- Maximum proton energy measured: ~85 MeV
- Laser-P^+ Conversion efficiency: ~10%
- Flux: 10^{10} Protons/MeV @ 10 MeV with broad thermal spectrum