Overview of Underpinning Technology Development on LhARA WP2

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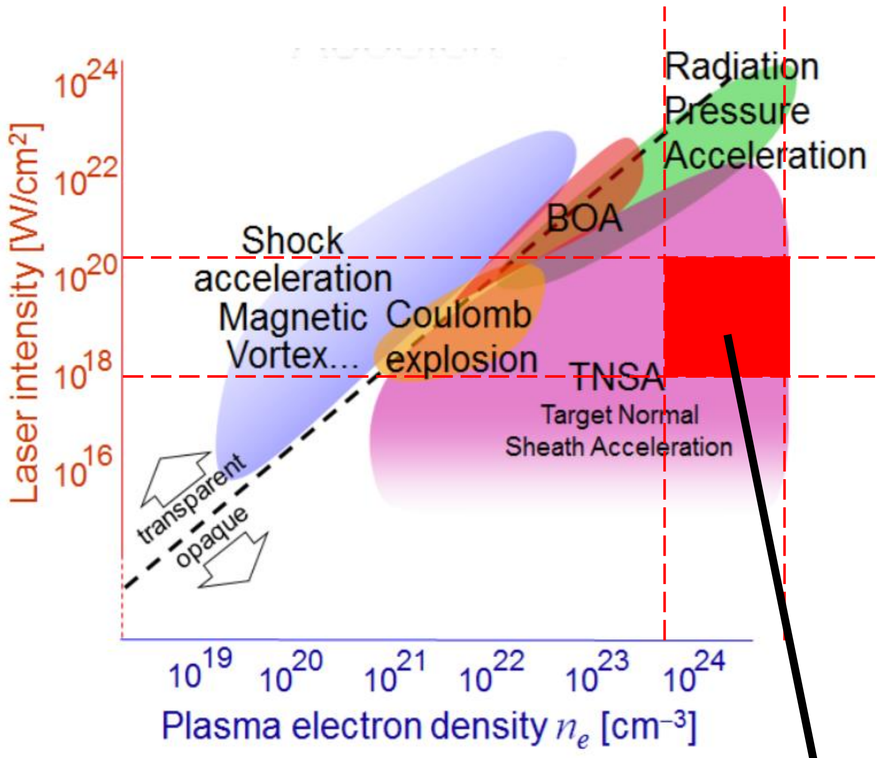
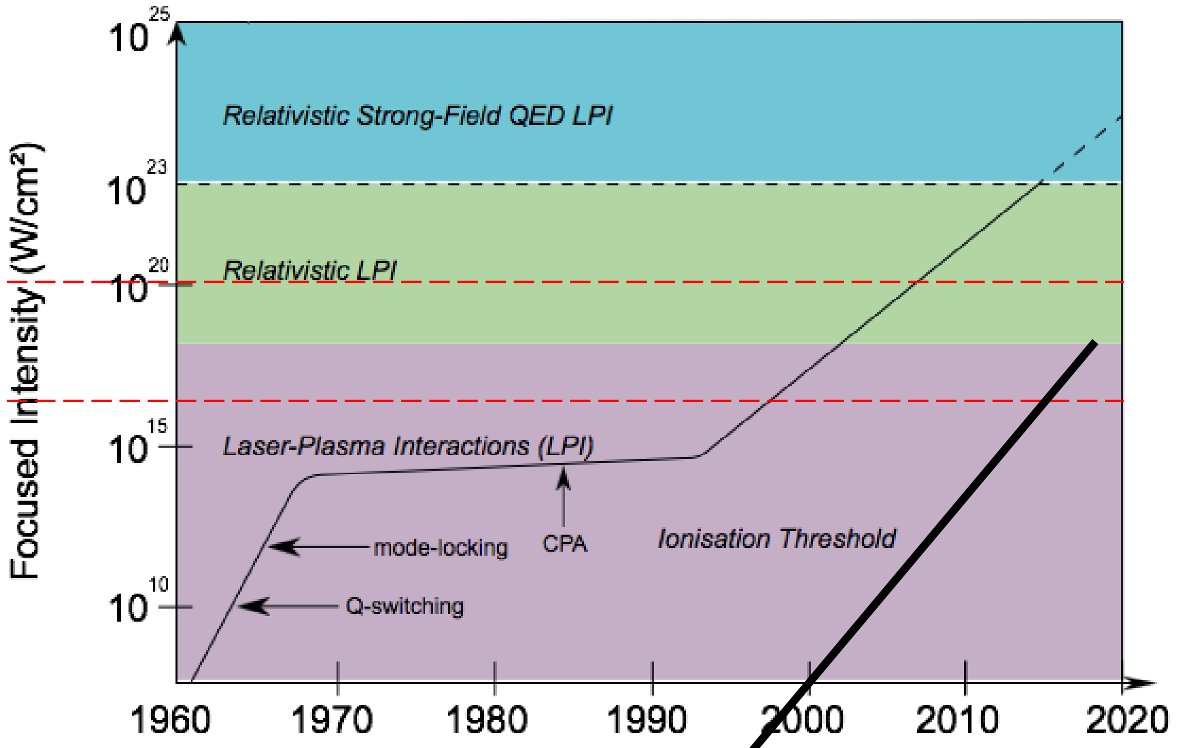
Laser driven ion acceleration…



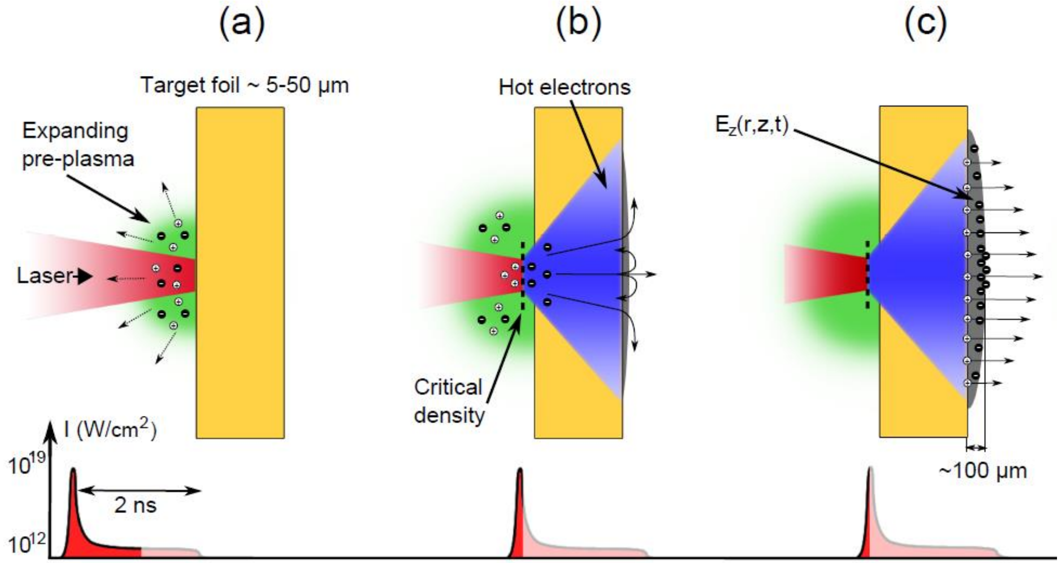


Well established, widely studied acceleration mechanism

University scale & commercially available laser systems

- There are various modes/mechanisms of ion acceleration we could aim for but TNSA is the most stable, most well developed and occurs in an intensity range which is now feasible at the university scale…

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



$$k_B T_e = mc^2 \left(\sqrt{1 + a_L^2} - 1 \right)$$

$$E_{\mathrm{max}} = 2 k_B T_{\mathrm{hot}} \ln^2 \left(\tau + \sqrt{1 + \tau^2} \right)$$

- **Fast electron temperature** and **fast electron density and total number** at the rear surface drive proton **spectral** characteristics
- Transport physics defined by **material, target properties** and **self generated fields** drive proton **spatial** characteristics
- These are sensitive to a wide range of input parameters:

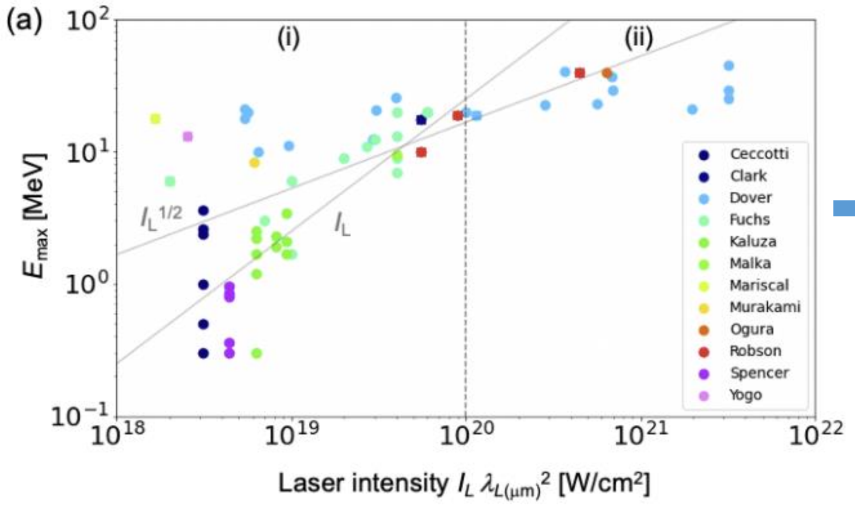
Laser:
- Intensity
- Energy
- Focal spot size
- Laser intensity contrast
- Polarisation
- …

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

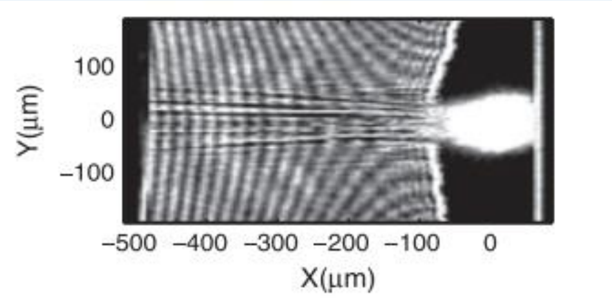
→

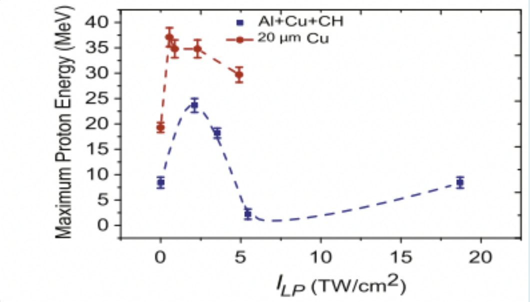
Experimental Implementation
- Focusing geometry
- Target Design
- Laser intensity contrast
- Polarisation
- Pulse duration
- …

Advances in understanding and controlling TNSA ion acceleration in the past decade

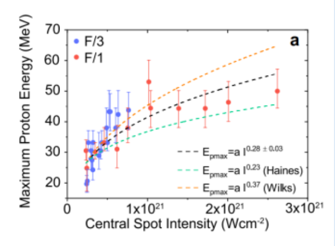


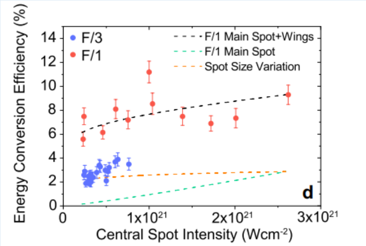
Role of pre-plasma scalelength/laser intensity contrast





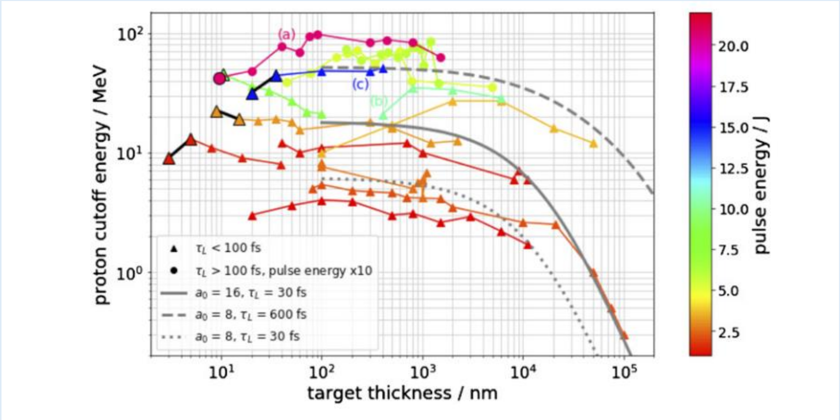
Effect of focal spot size and quality





R. Wilson *et al.* , *Sci Rep* volume 12, 1910 (2022)

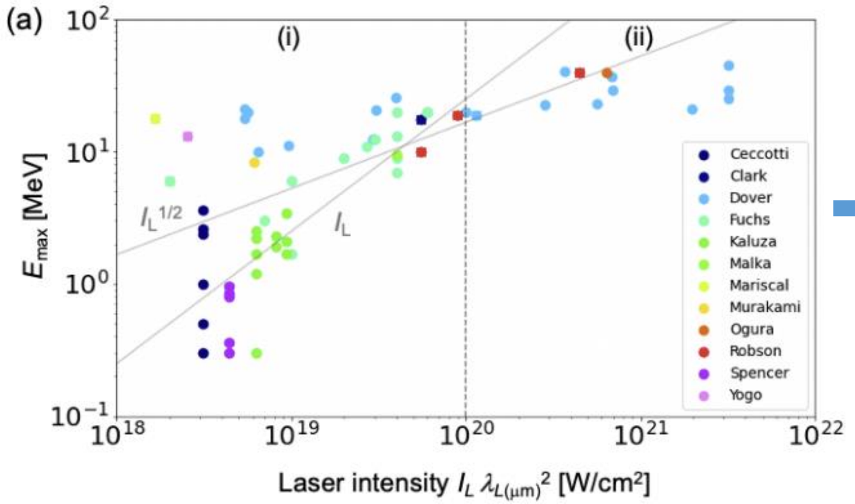
Role of target thickness



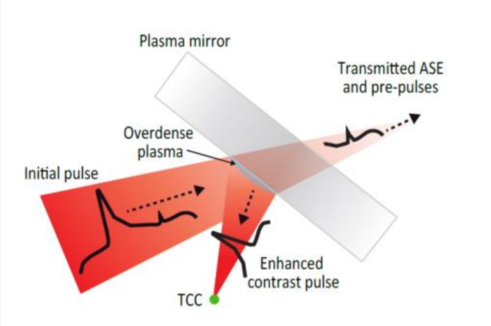
F. Albert *et al.,* New J. Phys. 23 (2021) 031101

Many, many other papers in the literature!

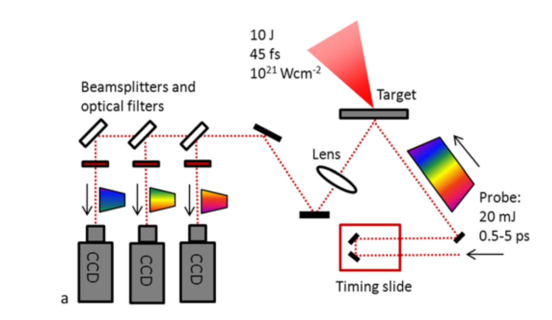
Underpinning technologies to control and optimise TNSA for LhARA



Role of pre-plasma scalelength/laser intensity contrast

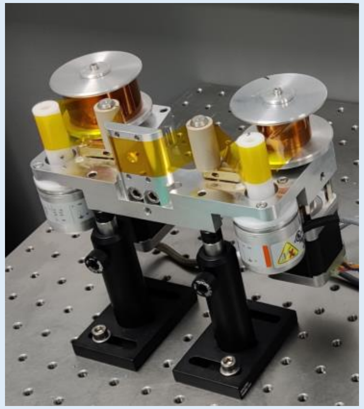


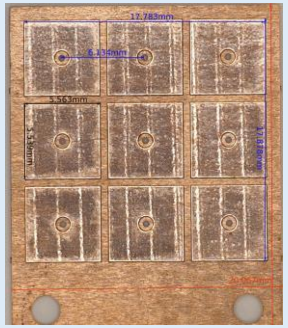
Plasma Mirrors



Advanced Optical Probes

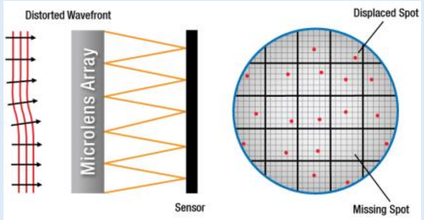
Role of target thickness





Advanced targetry (e.g Tape)

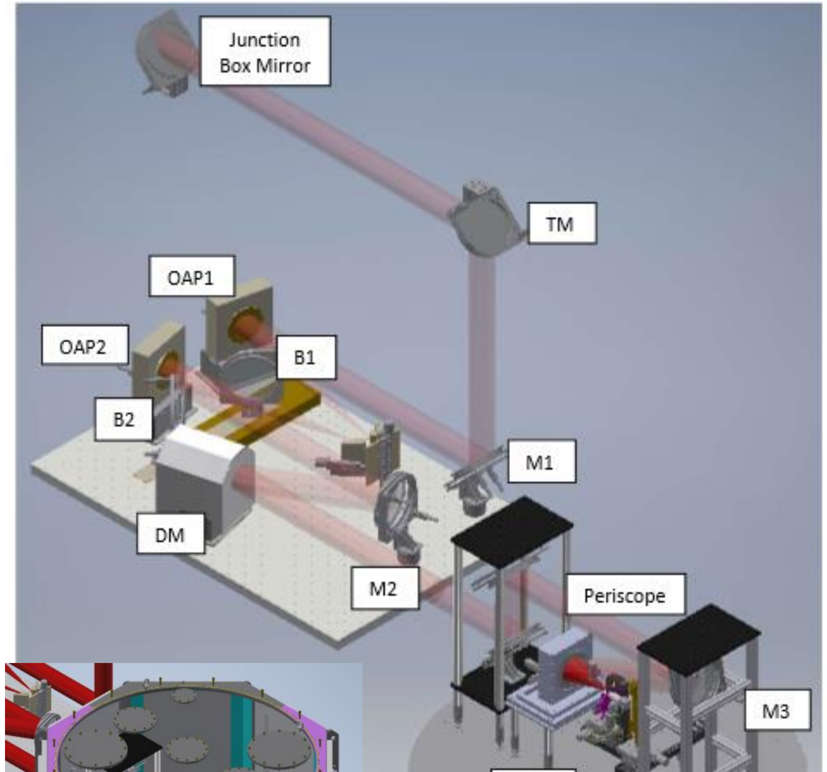
Effect of focal spot size and quality

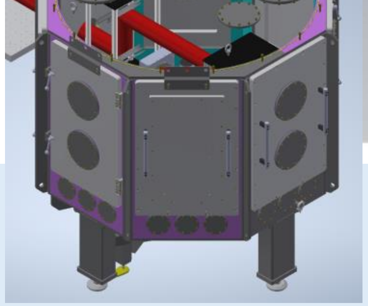


Adaptive optics

SCAPA: Scottish Centre for Application of Plasma based Accelerators

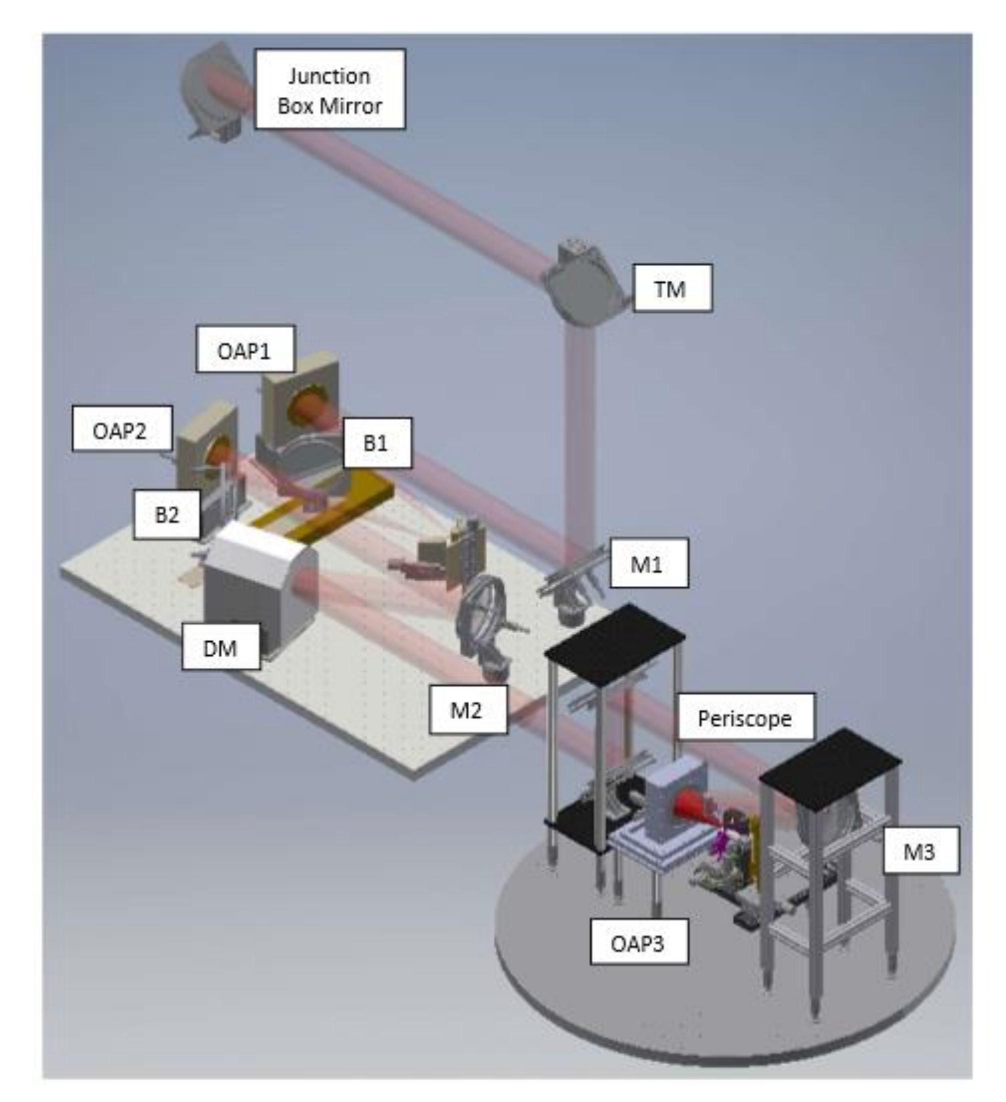
Laser-solid interaction beamline B1 in Bunker B.

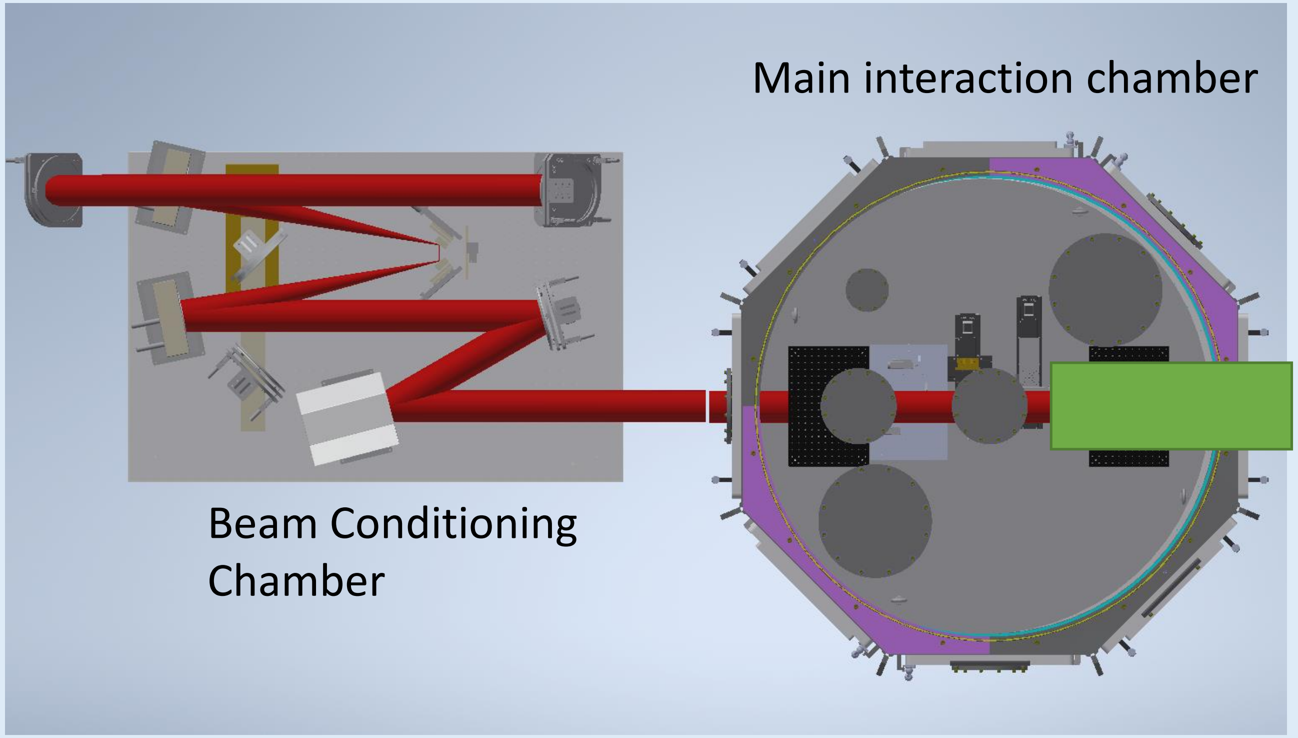




- 8 J, 25 fs at 5 Hz repetition rate up to ~10^{20} W/cm^2
- We would expect ~30 MeV proton beams
- Three experimental areas (A,B,C) with Bunker B dedicated to ion acceleration
- Two distinct vacuum chambers for beam conditioning and another variable experimental configurations.

SCAPA: Scottish Centre for Application of Plasma based Accelerators





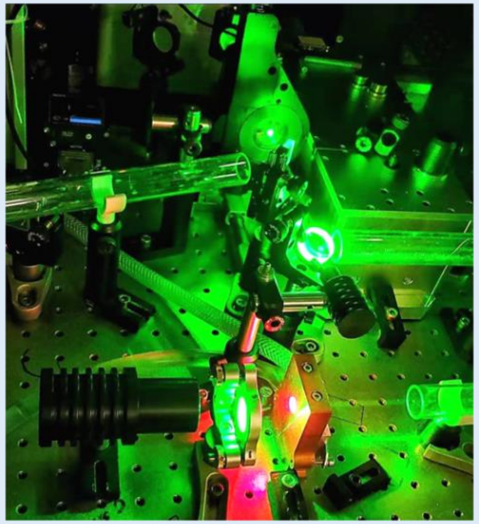
Region available for capture testing

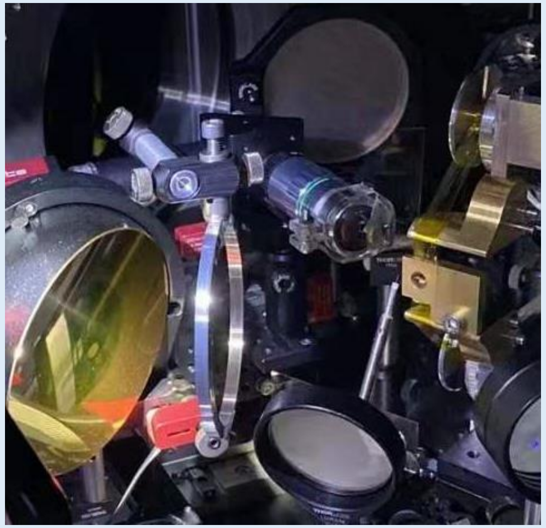
LhARA relevant lasers at Imperial College London

Cerberus laser (Prof. Roland Smith)

- Multibeam high energy, high power laser system
- Low energy high repetition (100 mJ at 10 Hz) or high energy low repetition (20 J at 0.001 Hz) , ~500 fs pulse length
- Regularly used as driver of laser proton source exceeding 5 MeV

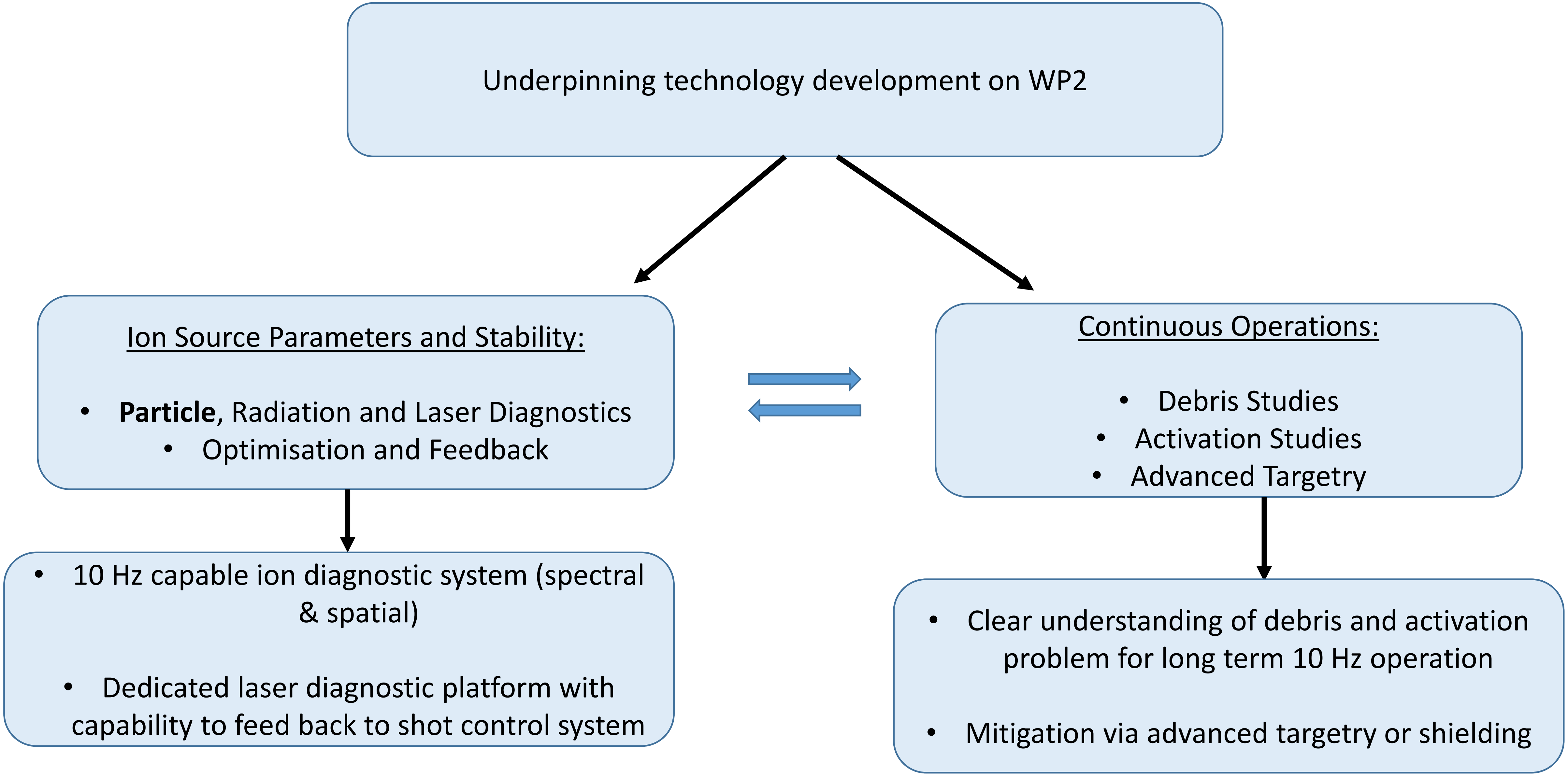
Zhi laser (Prof. Zulfikar Najmudin)





- Newly commissioned high repetition rate system
- Up to 200 mJ at 100 Hz operation , ~40 fs pulse length
- Ready for application to ion generation with expected energies > 2 MeV

WP2 Technology Development Programme:



Experiments & Technology Development in 2-year Programme: Characterising Source and Benchmarking Simulations

Established Diagnostics…

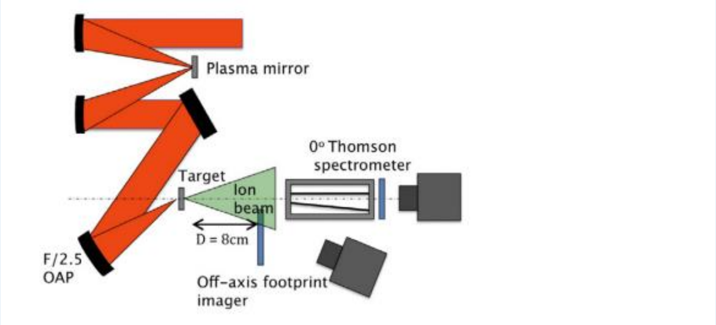
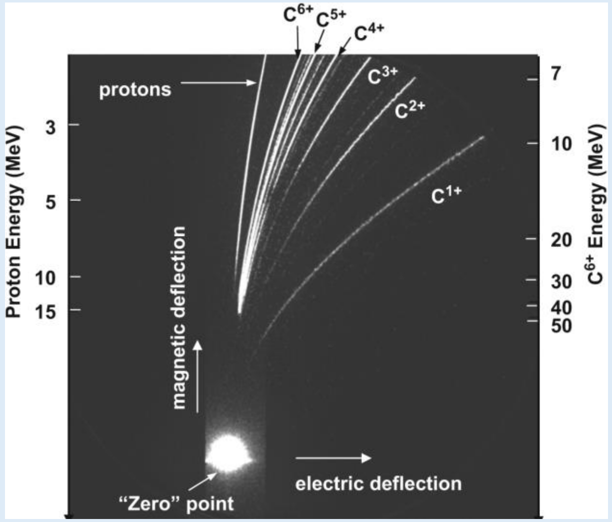


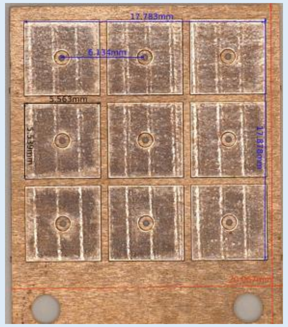
Figure 1. Experimental setup. A Thomson spectrometer deflects the ions onto a piece of plastic scintillator, which is imaged using an EMCCD camera. A second sheet of scintillator images the off-axis portion (>6° off-target normal) of the ion beam.

J.S Green *et al.,* NJP. 12 (2010) 085012

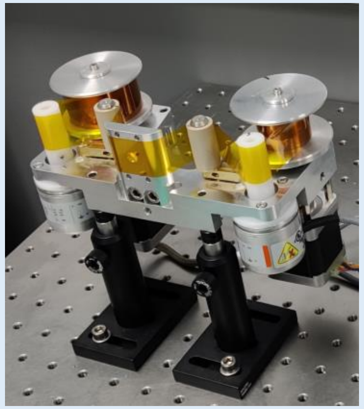


R. Prasad *et al.,* Nucl. Instrum. Methods. 623.2 (2010): 712-715.

Established Targetry…moving toward Hz-level targetry



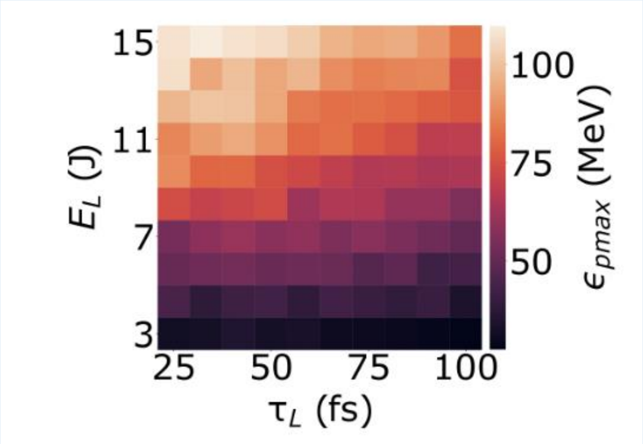
Typical 9-target array



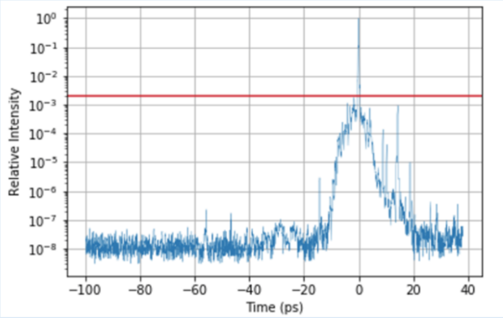
Tape targetry system (online in SCAPA 2022)

….to build a systematic parameter space map of the source performance

- Energy, Flux, Divergence across multiple ion species

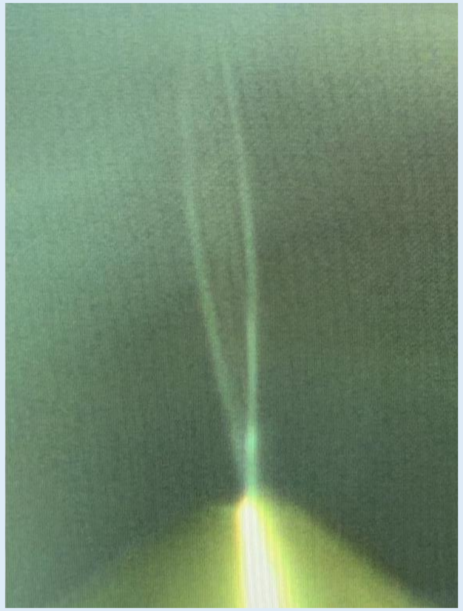


..but also need to consider some other experimental contributions like temporal contrast



Experiments & Technology Development in 3-year Programme: Producing a stable, high-rep source

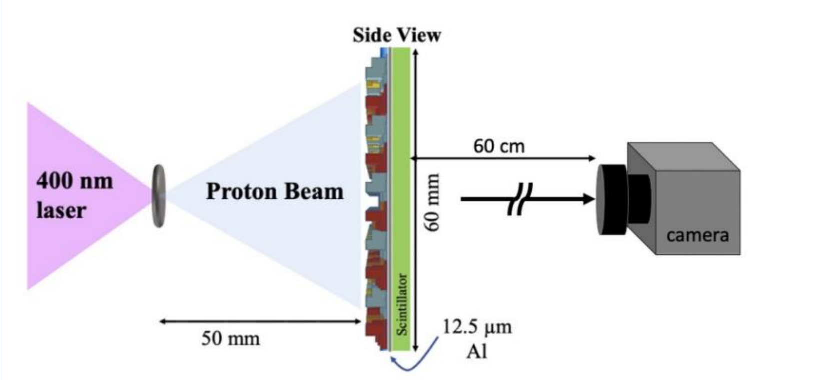
Novel Liquid Targetry



Courtesy of C. Palmer

- Reduces production of debris
- Increases operational time and possible rep rate

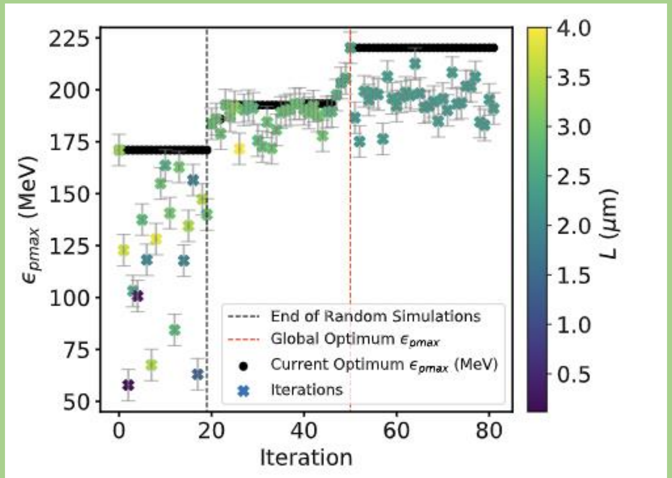
Advanced Particle & Laser Diagnostics



D. Marsical *et al.* , Plasma Phys. Control. Fusion 63 (2021) 114003

- Implementation of advanced (existing) particle diagnostics, taking account of long term operation.
- Implementation of full laser diagnostic suite to support automation, stabilisation.

ML/AI Control & Optimisation



- Application of ML techniques (e.g Bayesian Optimisation) for parameter space
- Application of AI techniques (DNNs, CNNs) for system control and virtual diagnostics

Summary

- Laser-Ion acceleration driven by the TNSA mechanism is now well established and key underpinning physics is well understood

- Advances in lasers, diagnostics, targets now make a stable, source of laser-driven ions practicable

- Our 2-year programme will use lasers at Imperial College and Stathclyde to demonstrate and benchmark an ion source within LhARA constraints

- A 3-year programme will aim to implement an actively stabilised ion source within constraints that can operate at Hz-level for hour long periods by making use of advanced targetry, ML/AI and diagnostics.

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