



Experiments & Technology Development on LhARA WP2

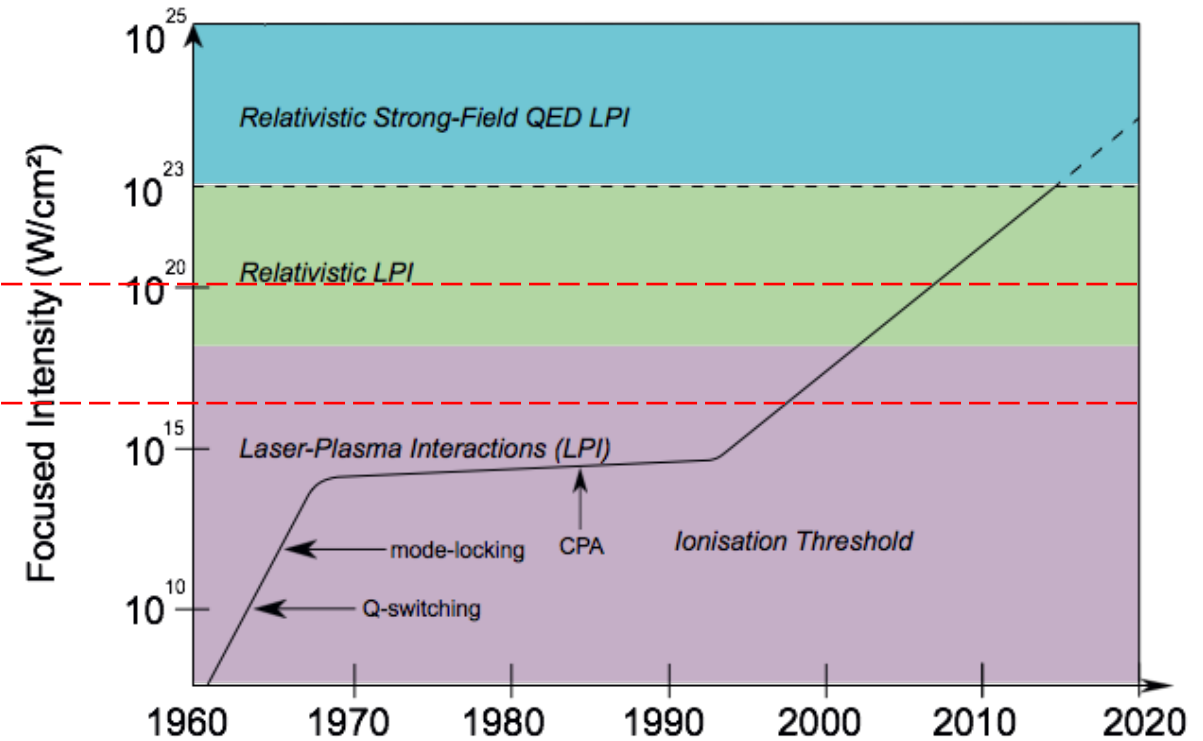
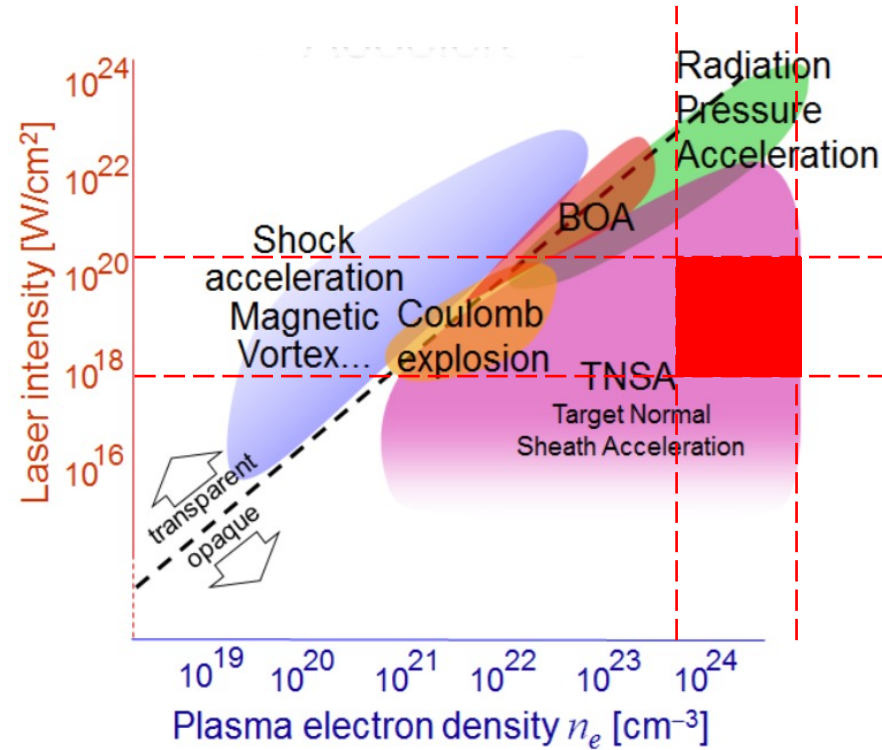
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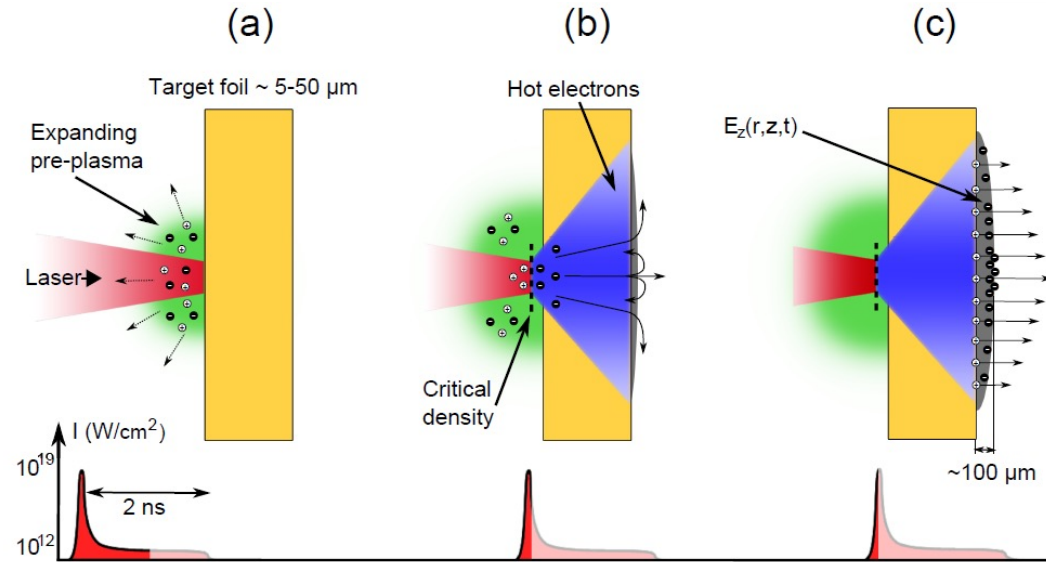
15th December 2021

Laser driven ion acceleration...



- 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)



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

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

- **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:

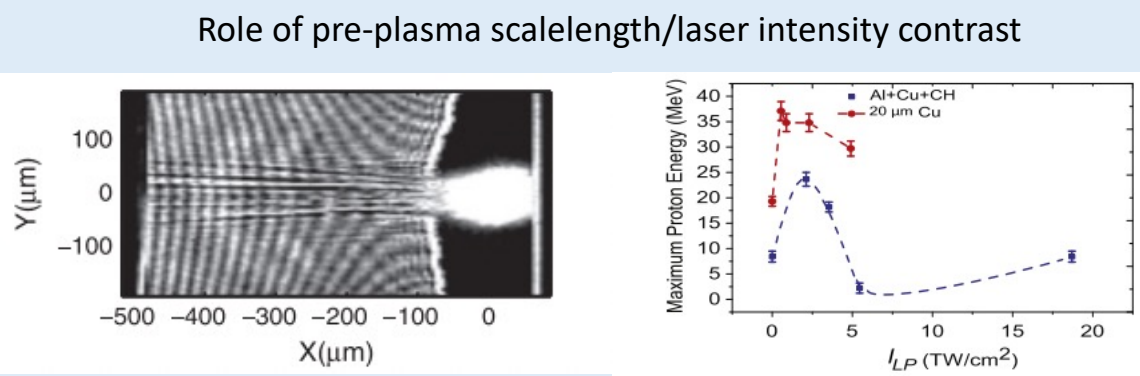
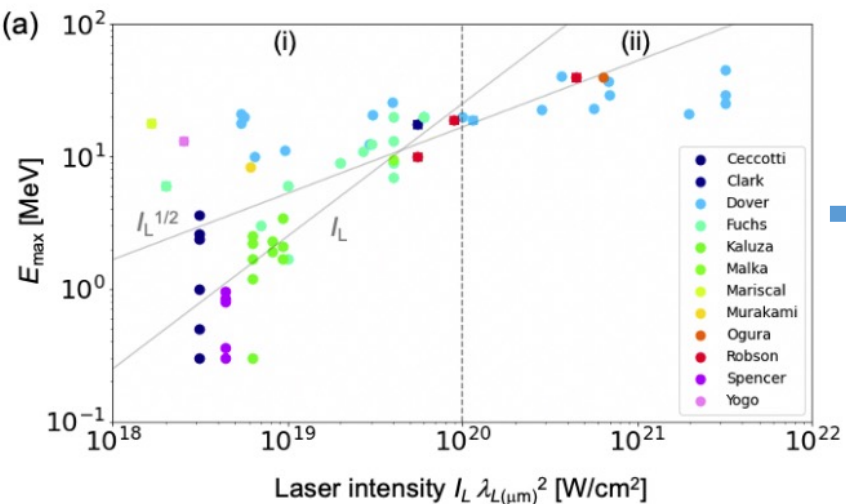
- Energy conversion efficiency
- Fast electron divergence angle
- Z (scattering, resistivity)
- Preplasma scale length
- Incidence angle
- ...



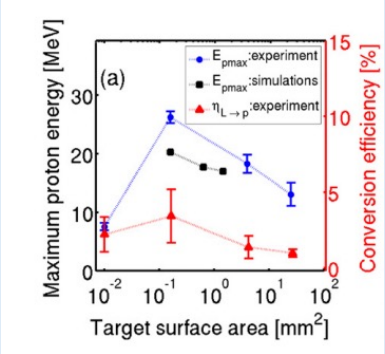
Experimental Implementation

- Focusing geometry
- Target Design
- Laser intensity contrast
- Polarisation
- Pulse duration
- ...

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

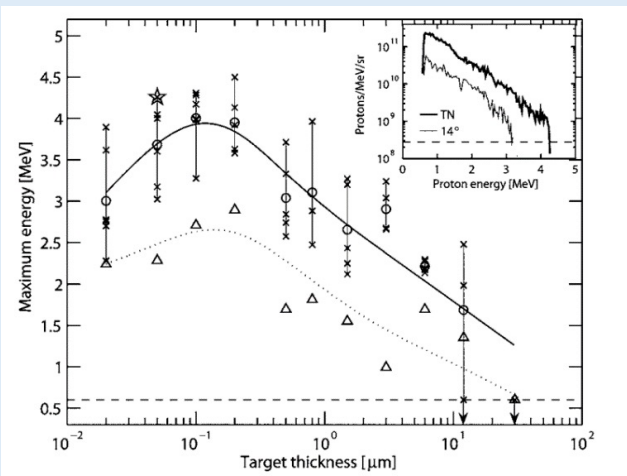


Effect of 'lateral transport' and target dimensions



S. Buffechoux et al., Phys. Rev. Lett. **105**, 015005 (2010)
O Tresca et al 2011 Plasma Phys. Control. Fusion **53** 105008 (2011)

Role of target thickness

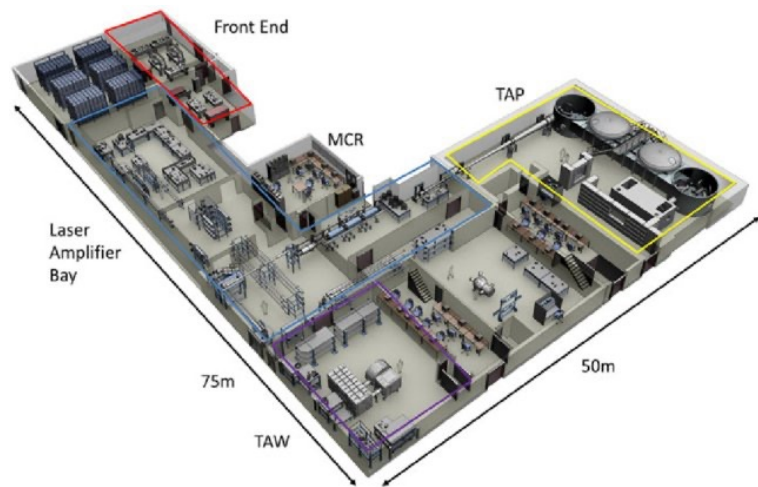


D. Neely et al., Appl. Phys. Lett. **89**, 021502 (2006)

Many, many other papers in the literature!

Critical advances in the underpinning technology now enabling significant advances in laser-driven ion acceleration...

Lasers

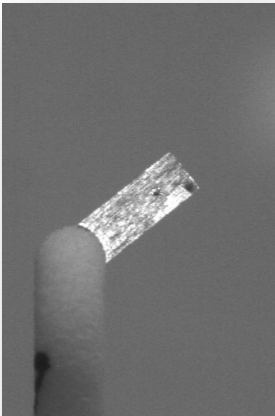


1 pulse/ 30 mins



10+ Hz

Targets

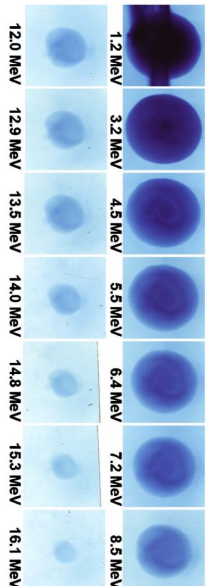


Hand made targets



Mass manufacture,
tape targets, liquid
targets

Diagnostics



Film based/slow
readout diagnostics



Scintillator based,
10+ Hz readout

Simulations/Computation



Physics/dimensionally
limited models/limited
access to HPC

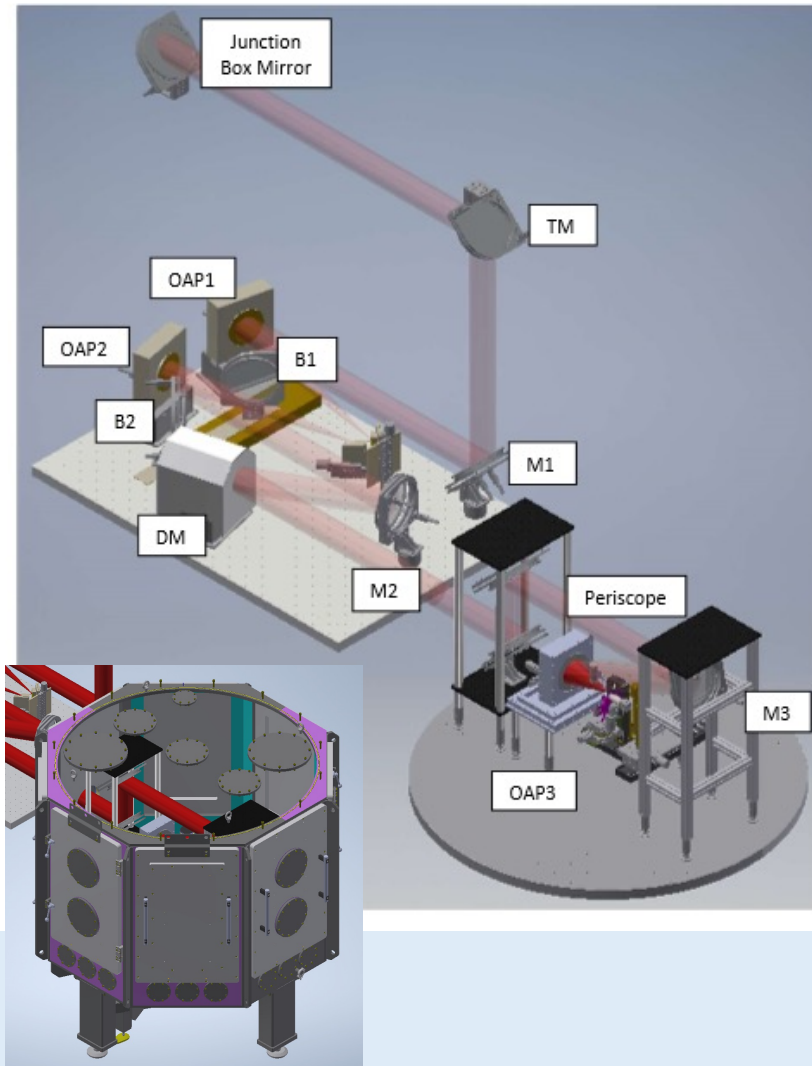


Improved, more
efficient models,
wider access to HPC

SCAPA: Scottish Centre for Application of Plasma based Accelerators

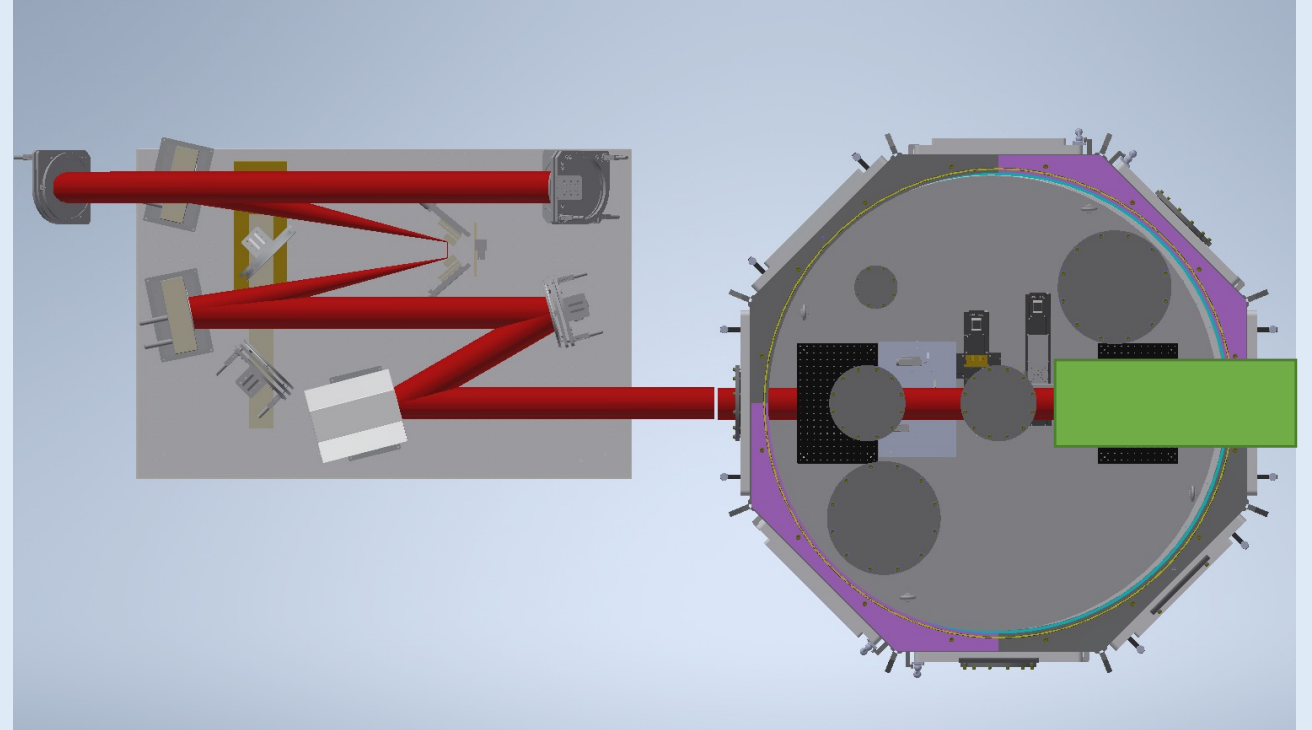
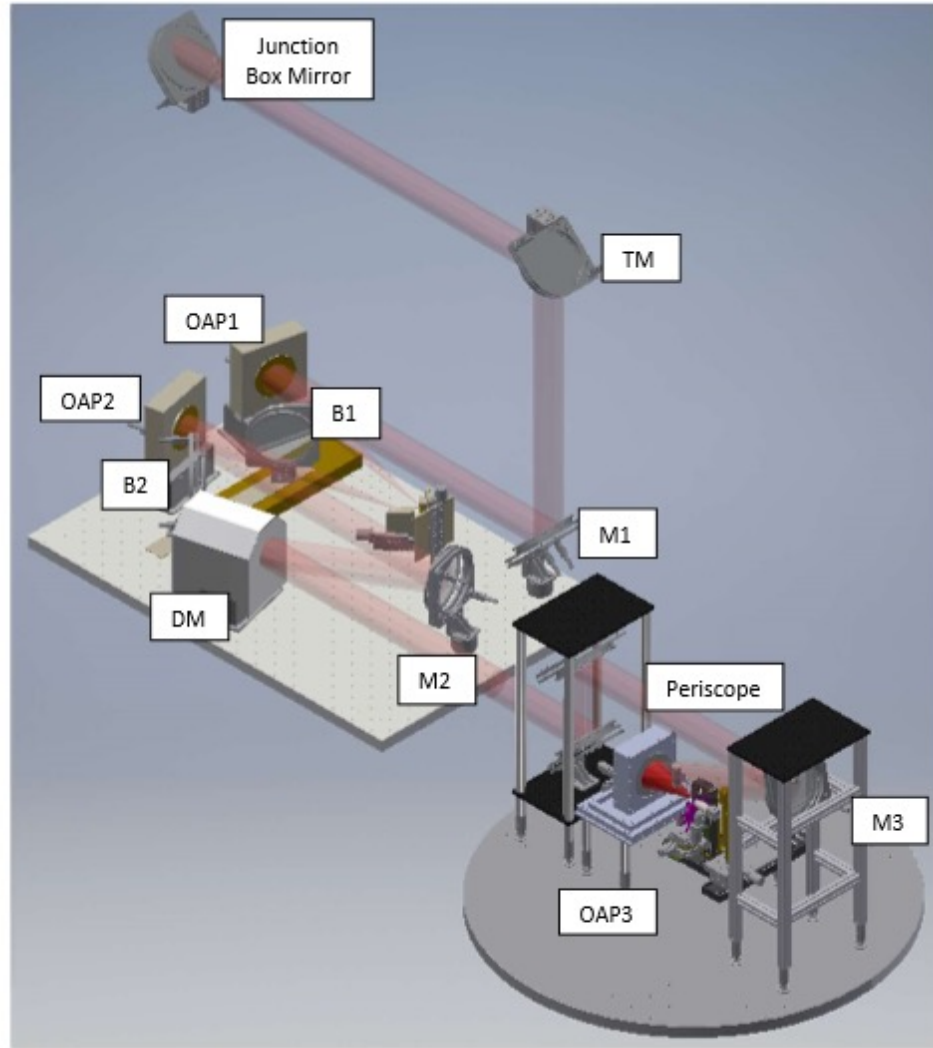


Laser-solid interaction beamline B1 in Bunker B.



- 8 J, 25 fs at 5 Hz repetition rate up to $\sim 10^{20}$ W/cm²
- 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

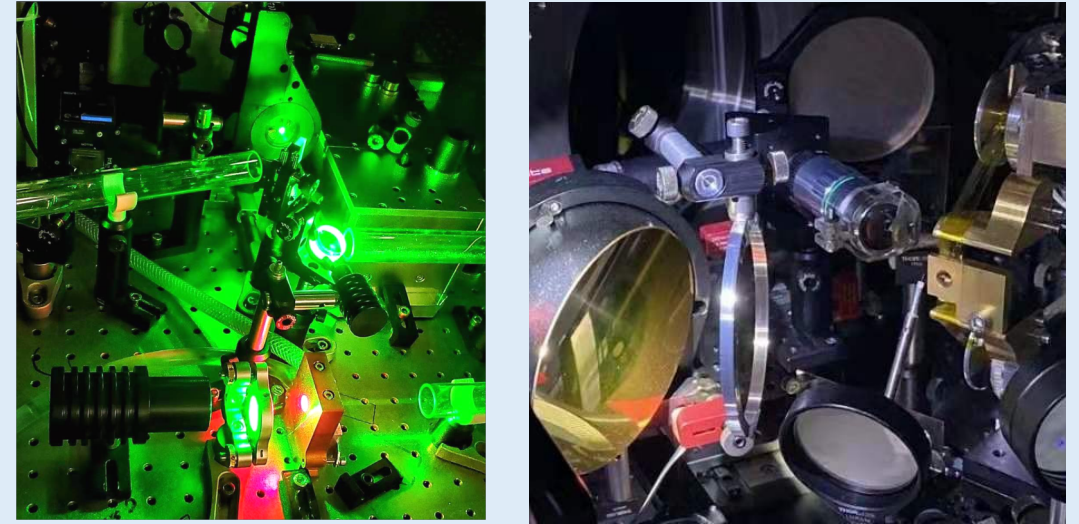
LhARA relevant lasers at Imperial College London

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

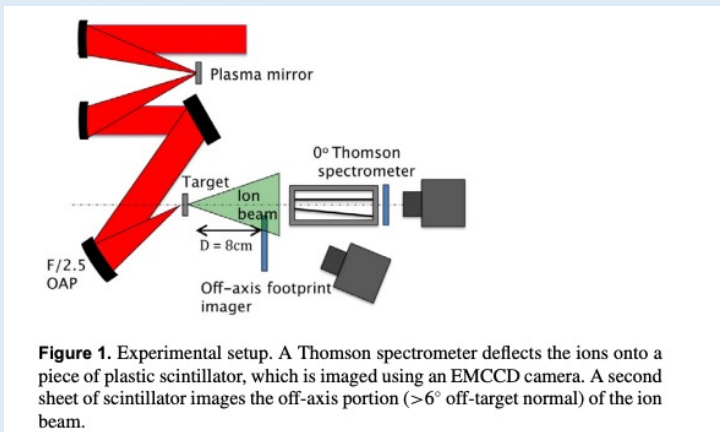
Zhi laser (Prof. Zulfikar Najmudin)



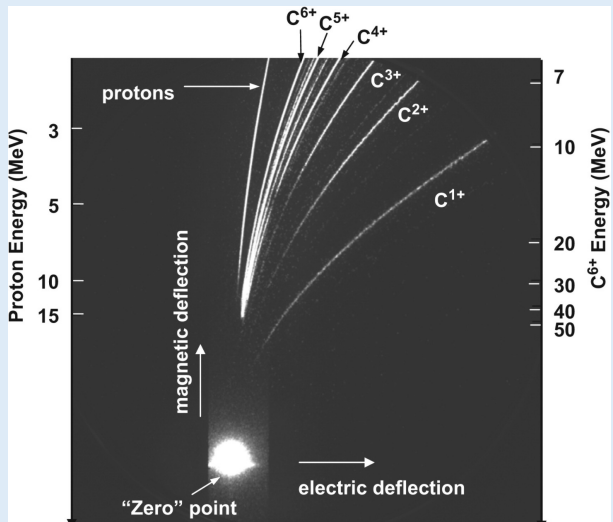
- Newly commissioned high repetition rate system
- Up to 200 mJ at 100 Hz operation, ~40 fs pulse length
- Ready for application to ion generation with expected energies > 2 MeV

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

Established Diagnostics...

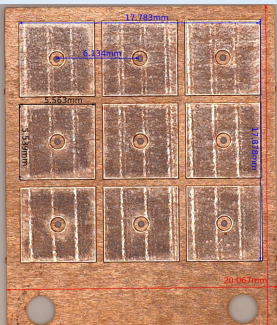


J.S Green *et al.*, NJP. 12 (2010) 085012

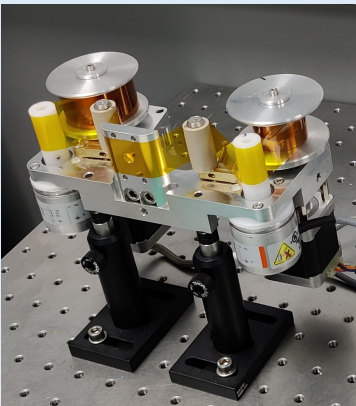


R. Prasad *et al.*, Nucl. Instrum. Methods. 623.2 (2010): 712-715.

Established Targetry...moving toward Hz-level targetry



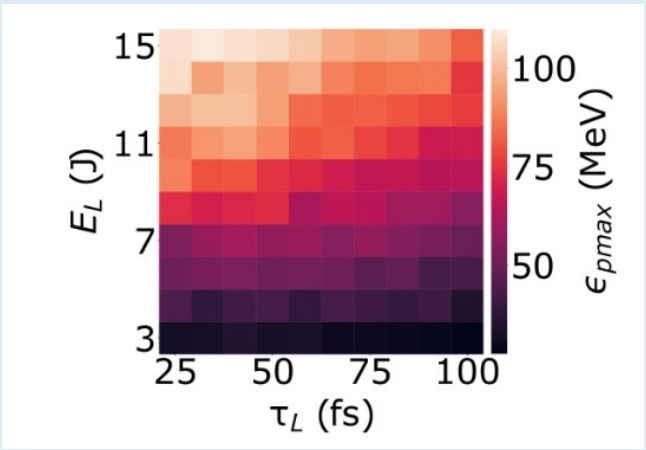
Typical 9-target array



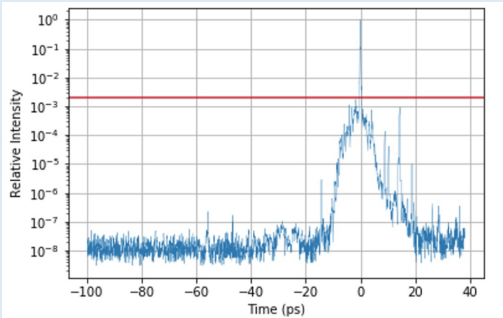
Tape targetry system (online in SCAPA 2022)

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

- Energy, Flux, Divergence across multiple ion species

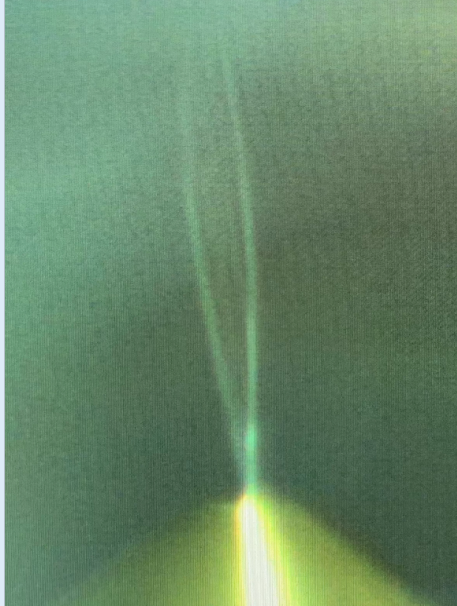


..but also need to consider some other experimental contributions like temporal contrast



Experiments & Technology Development in 5-year Programme: Producing a stable, high-rep source

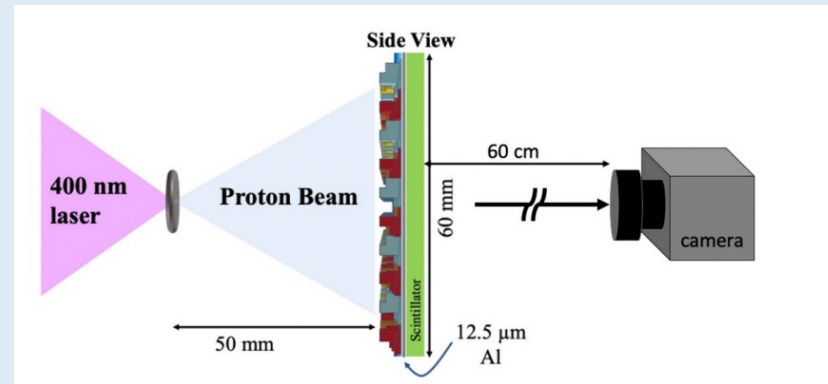
Novel Liquid Targetry



Courtesy of C. Palmer

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

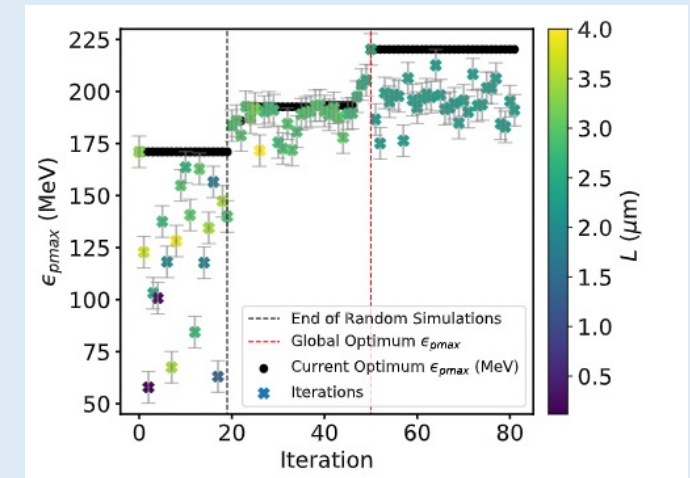
Advanced Particle & Laser Diagnostics



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



E. Dolier et al, In preparation

- 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 and computation now make a stable, source of laser-driven ions practicable
- We propose a 2-year programme using lasers at Imperial College and Stathclyde to demonstrate and benchmark an ion source within Lhara constraints
- A 5-year programme (running in parallel subject to availability of funding) 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.