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LhARA Collaboration Meeting #5

WP2 Source Session

Update on SCAPA Development and Experiments

26th April 2024

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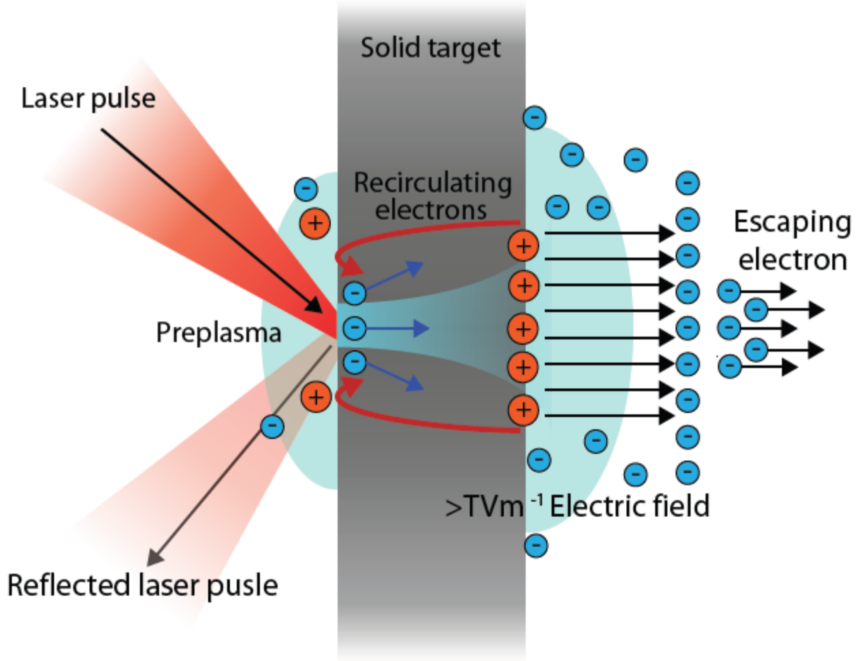
Considerations for a laser driven proton source from Target Normal Sheath Acceleration mechanism (TNSA)



Laser energy absorbed producing large population of hot electrons

↓

Hot electrons injected and propagate through the target

↓

Generates strong (~TV/m) electrostatic sheath fields at target rear

↓

Drives acceleration of high energy protons

- Sensitive to a wide range of input parameters:

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

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

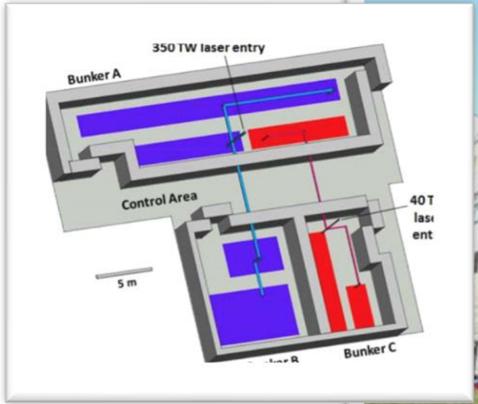
Experimental Implementation:
- Focusing geometry
- Target Design
- Laser intensity contrast
- Polarisation
- Pulse duration
- …

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

THE UNIVERSITY OF STRATHCLYDE

- Research is focused on the development and application of laser-driven particle acceleration.
- Can deliver high particle numbers ($>10^8$ protons), within the MeV energy range, at Hz level repetition rate.

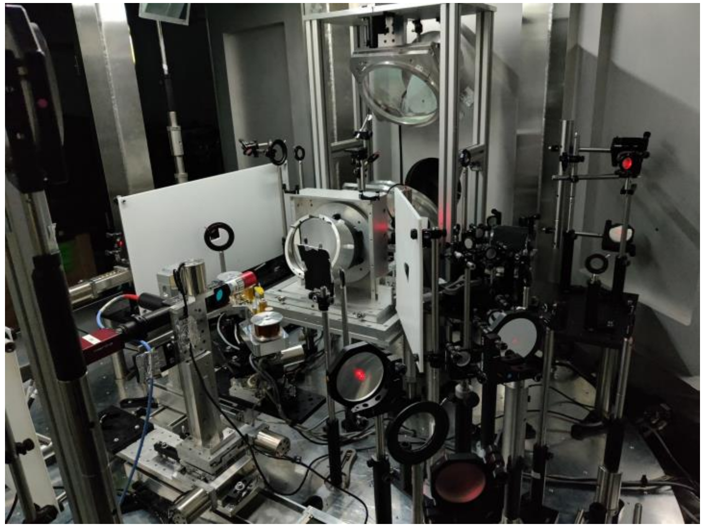
Parameters	
Peak Power	≥350 TW
FWHM pulse duration	≤25 fs
Energy per pulse (on target)	≥ 7 J
Pulse repetition rate	1 Hz
Temporal intensity contrast	10^{10}:1 @ 100 ps 10^{8}:1 @ 30 ps 10^{4}:1 @ 2 ps ASE contrast 10^{10}:1
Central wavelength	800 nm
Beam quality Strehl ratio	≥0.85

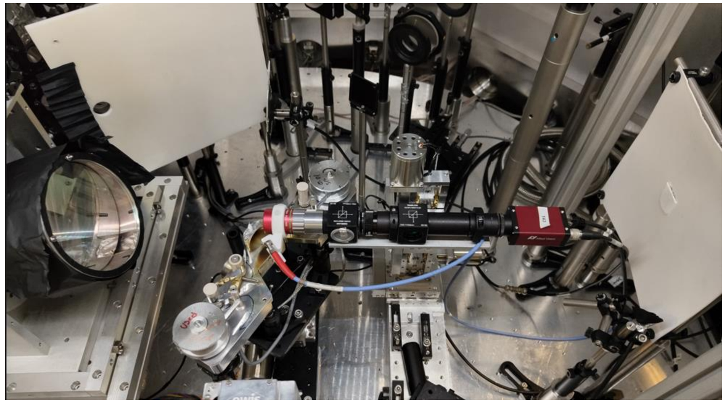


Laser-solid interaction beamline B1 in Bunker B.

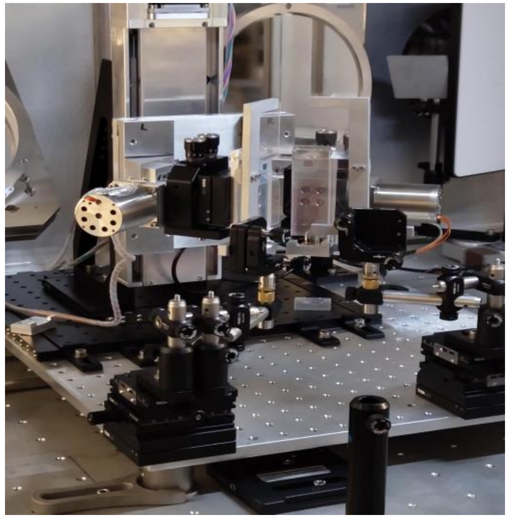
SCAPA Bunker B Target Station

Main Chamber Internals

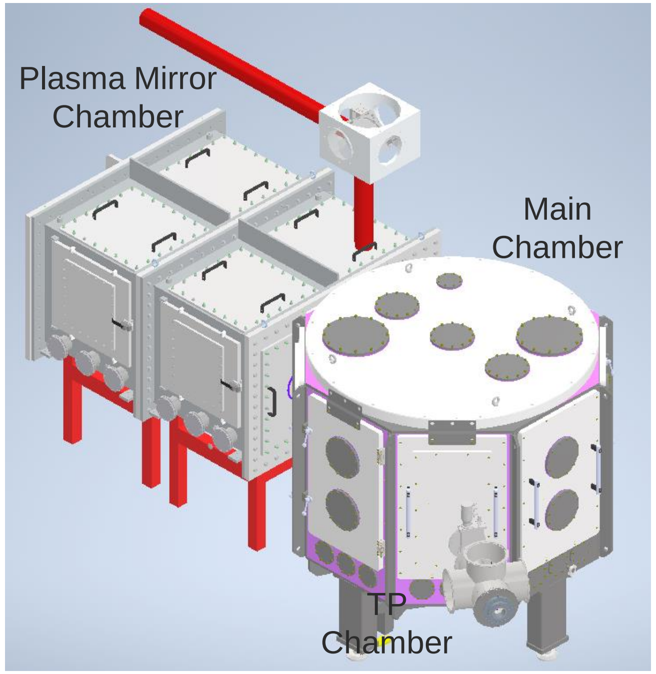


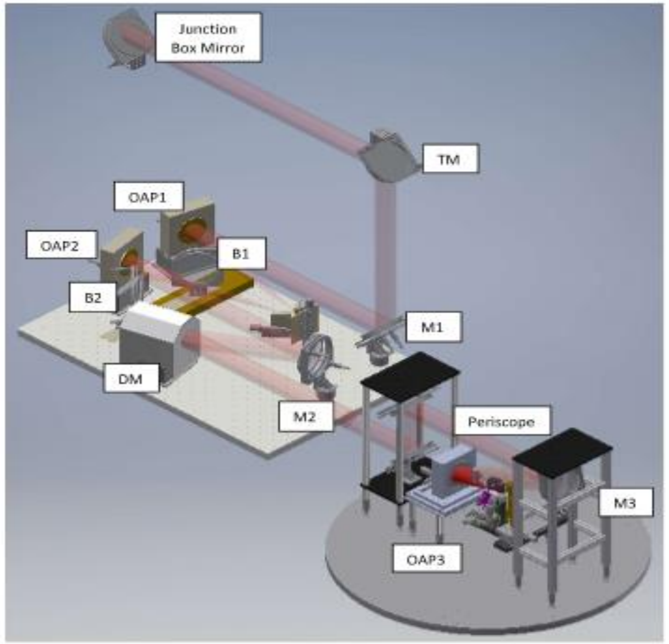


Plasma Mirror Chamber Internals



Beamline





Beamtime Updates

- Source setup now in semi-permeant state, with fixed beamline configuration and permanently setup diagnostics. Helps reduce time to begin taking measurements, improving stability, reliability and overall quality.

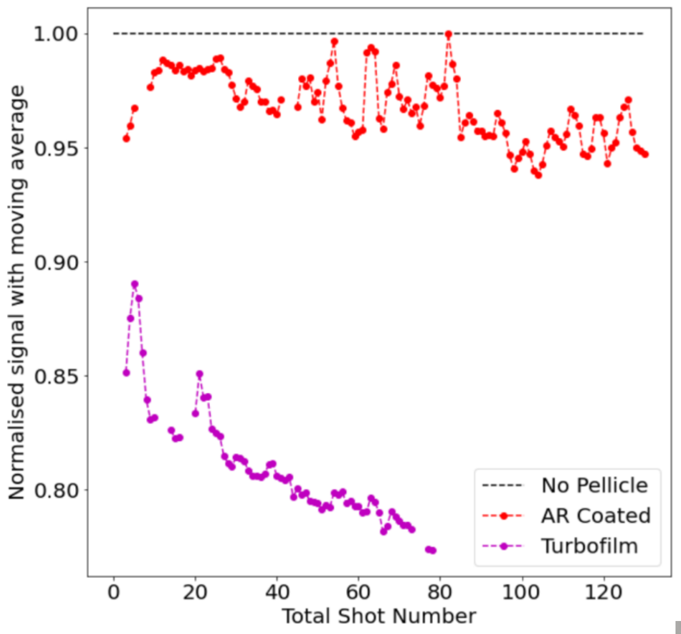
- Since the previous LhARA beamtime (July 2023) we have conducted three SCAPA commissioning beamtime slots;

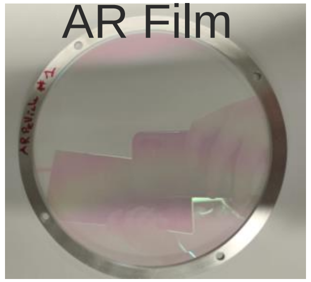
Beamtime	**Objective**
November 2023 – 1 Week Commissioning time	Transverse optical probe and preheater commissioning.
January 2024 – 1 Week Commissioning time	Control system and data capture tests/ Thomson parabola calibrations.
March 2024 -2 Week Commission time	Testing alternations to laser system (to improve beam spatial quality and temporal intensity contrast) on proton properties.

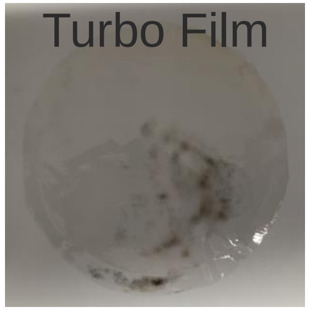
Setup Development Updates

i) OAP protection improvements

- Improved parabola protection, increased number of shots per pellicle optic and increased energy to target, with new AR coated pellicle.
- Does not damage as quickly as pervious pellicle (made from turbo film).

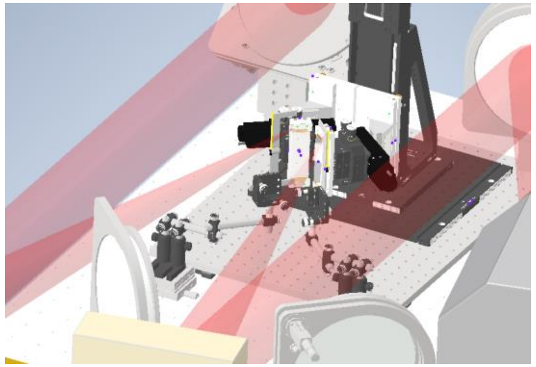


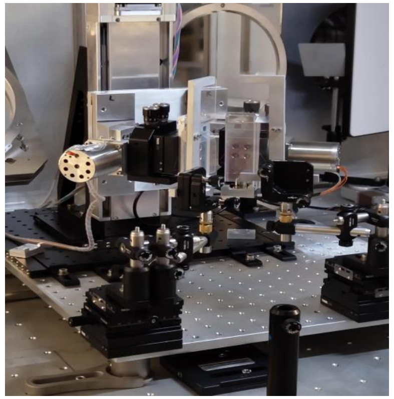


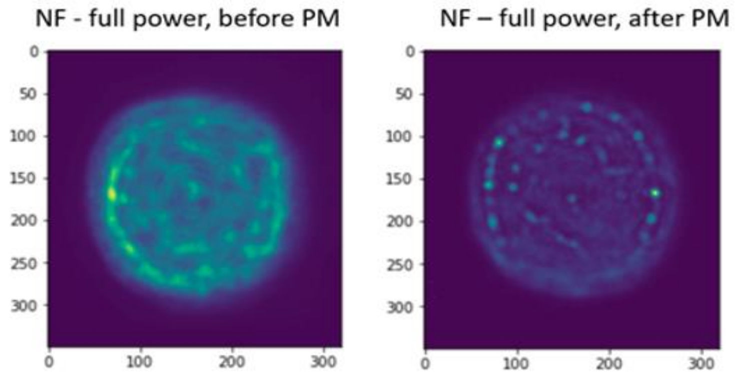


ii) Plasma mirror system

- Commissioning of a double plasma mirror system has begun.
- Employed to improve the laser pulse temporal-intensity contrast, enabling investigation of the influence of this on TNSA and irradiation of thinner targets.



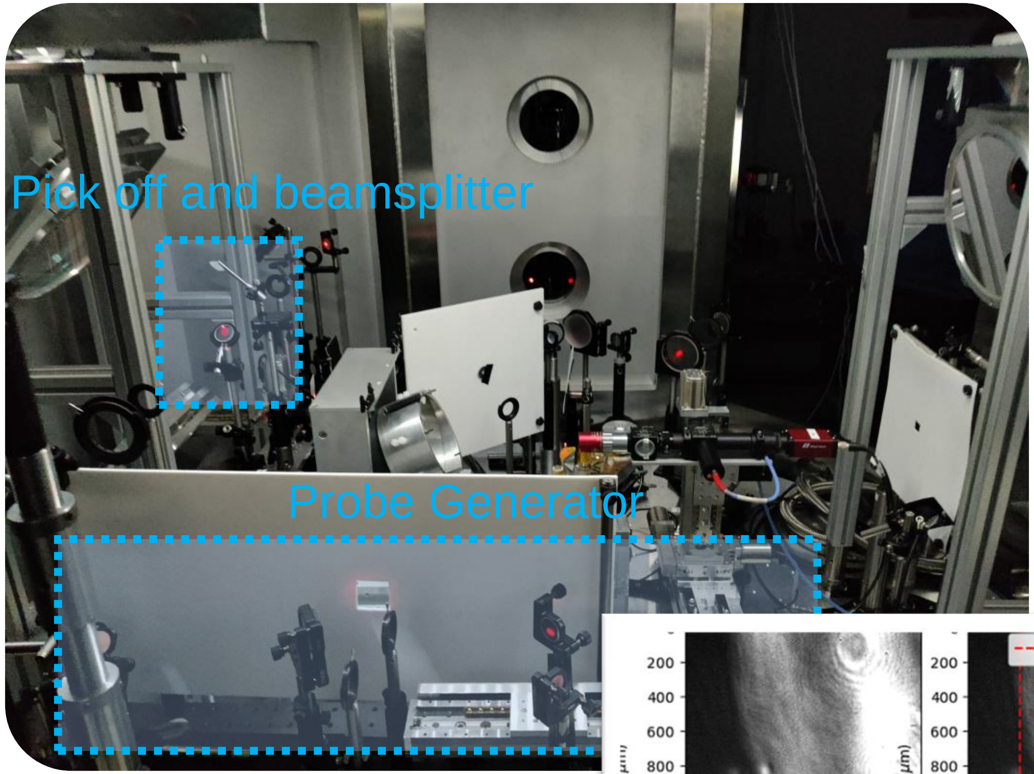


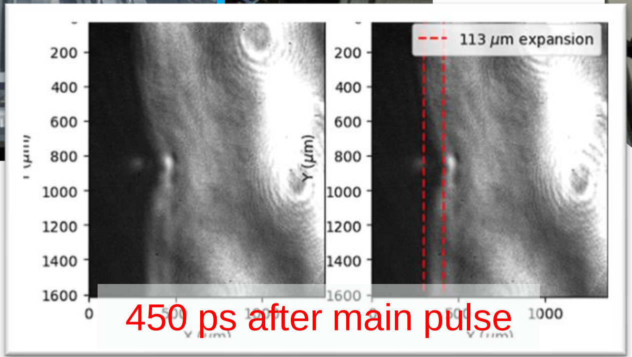


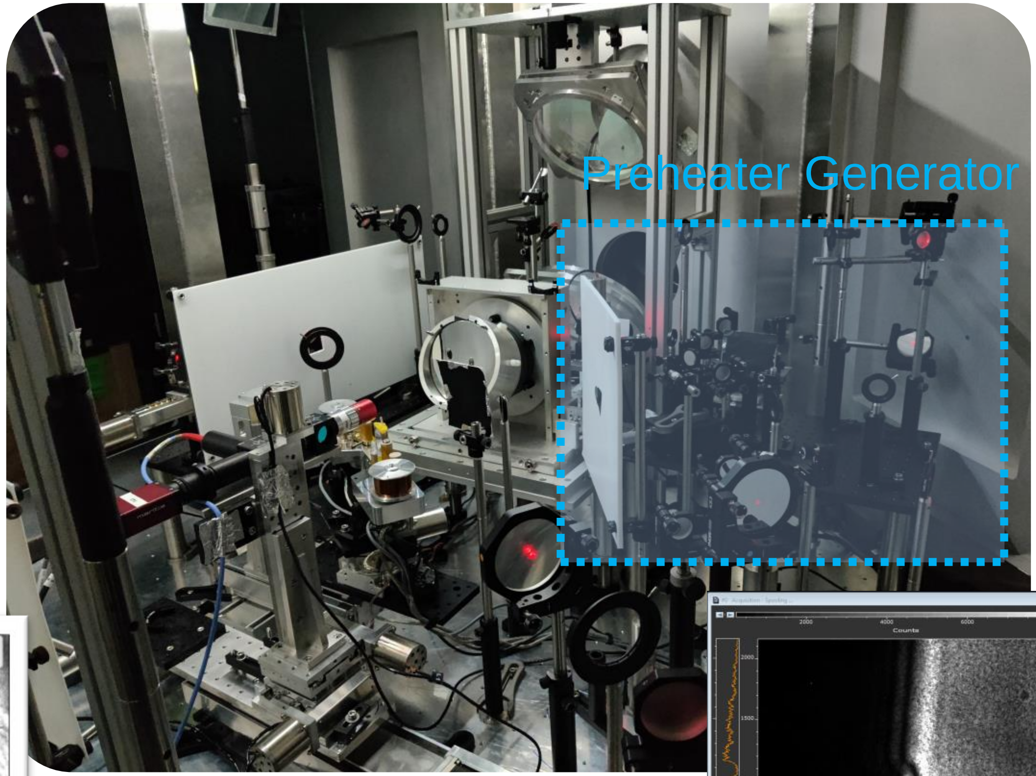
Setup Development Updates

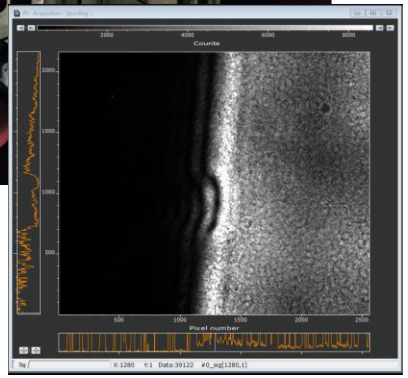
iii) Transverse optical probe and pre-plasma generator

- An optical probe and pre-heater beamline to monitor and control the front surface pre-plasma scale length has now been installed and commissioned. Both formed using a small sample of the main beam, guided to compact setups to alter their timing with respect to the main pulse.





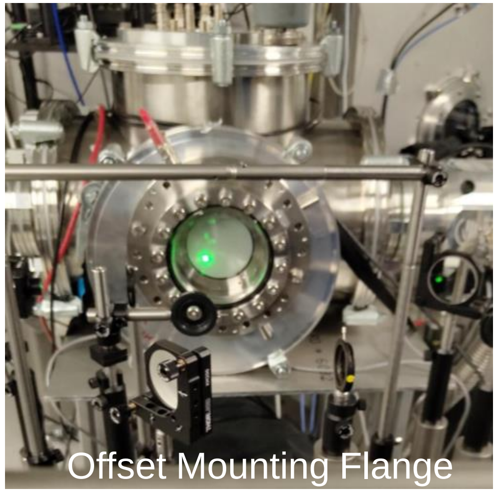


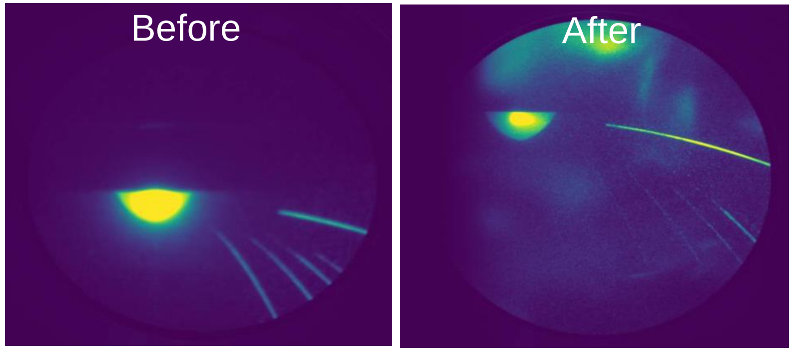


Diagnostic Updates

i) Thomson parabola ion spectrometer

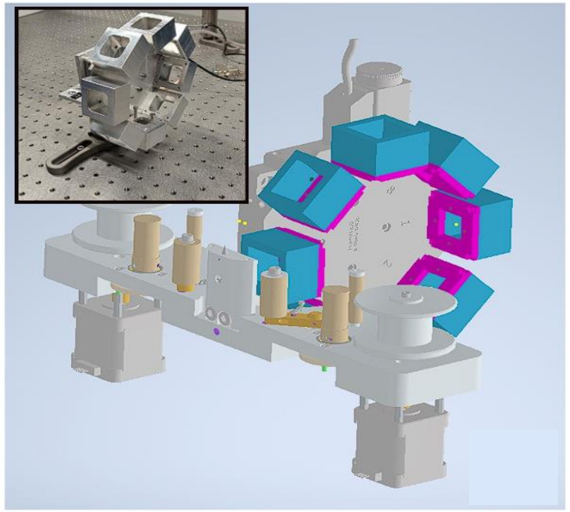
- Improved spectrometer measurable energy range and detector FOV, through modification of the detector (MCP mounting).
- Next key development is calibration of this diagnostic for proton numbers.

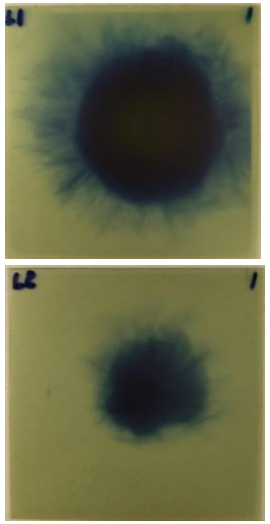




ii) Proton beam spatial/spectral diagnostics

- Developed a multi-shot radiochromic film stack 'wheel' for beam spatial/spectral measurements.
- PROBIES footprint monitor **(Matt Alderton will give an update on this next)**





Targetry Developments (working closely with CLF/EPAC collaborators)

i) Tape drive angled operation

- New modified tape drive configuration, enables use of focal spot camera to align target at a 35° angle.

ii) Tape alignment improvements

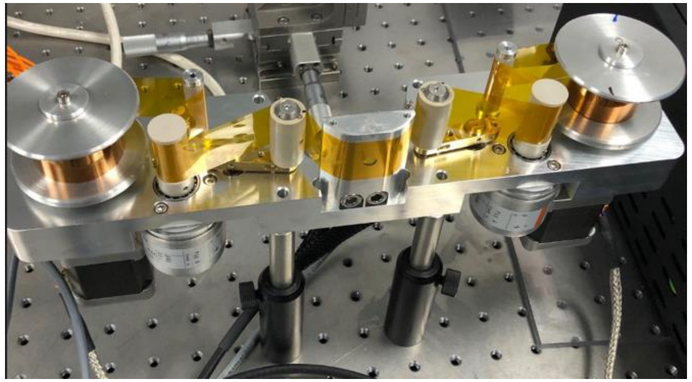
- Alignment issues employing target rear illumination at 35° angle have been solved using side angle illimitation with a fibre optic.

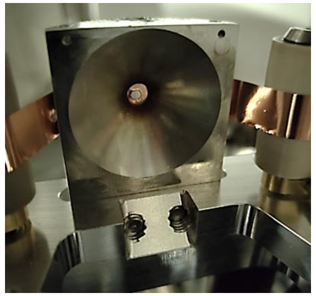
iii) Testing new tapes

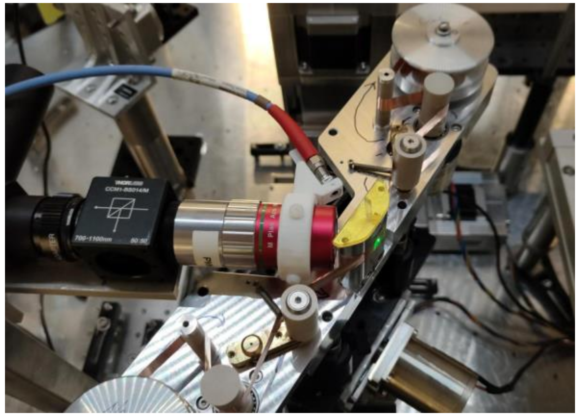
- Testing to-date has employed 25 µm Kapton (plastic) tape.
- Now conducting testing of thinner metals tapes (10 um steel)…however experiencing EMP and snapping issues.

iv) EMP mitigation

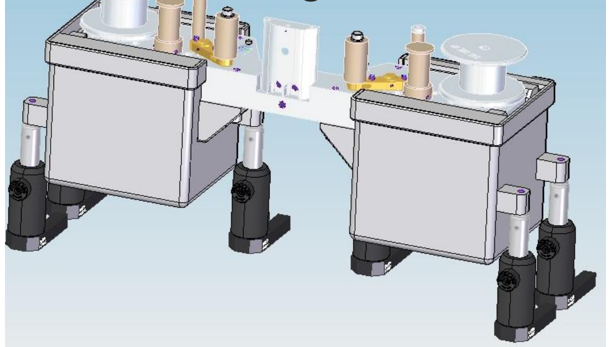
- Adding/testing EMP mitigations, including shielding tape drive components, using plastic isolation parts and shielding controller/increased distance from interaction.







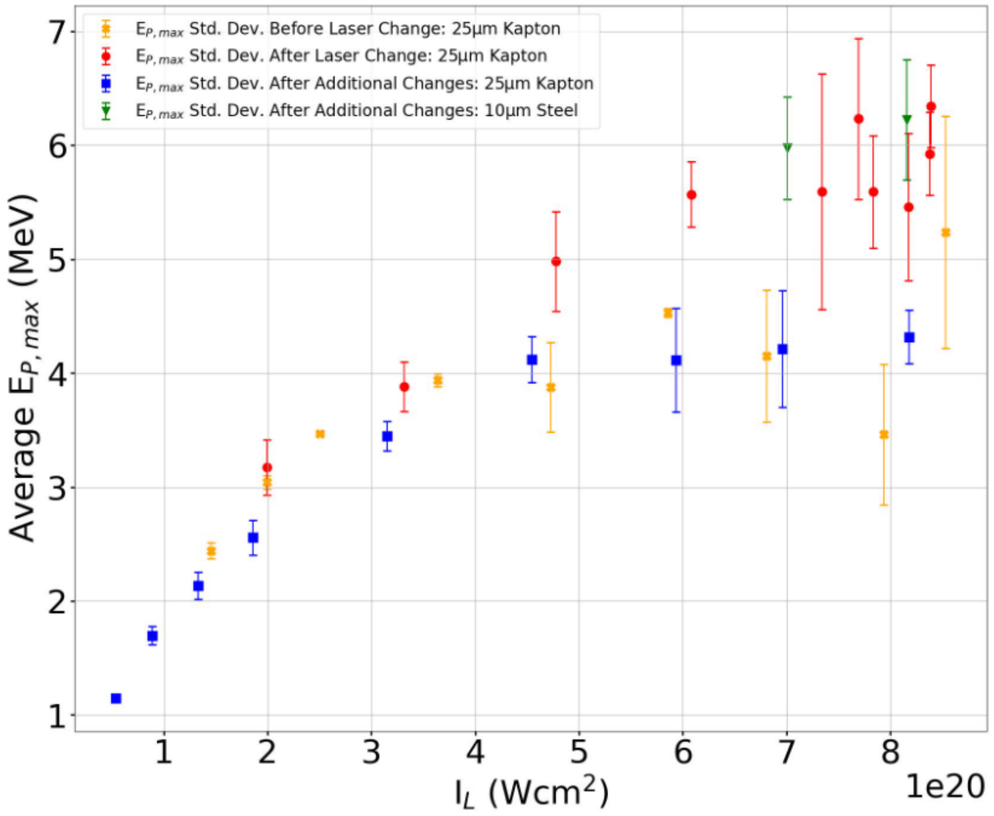
EMP Shielding modification



Source Development Updates

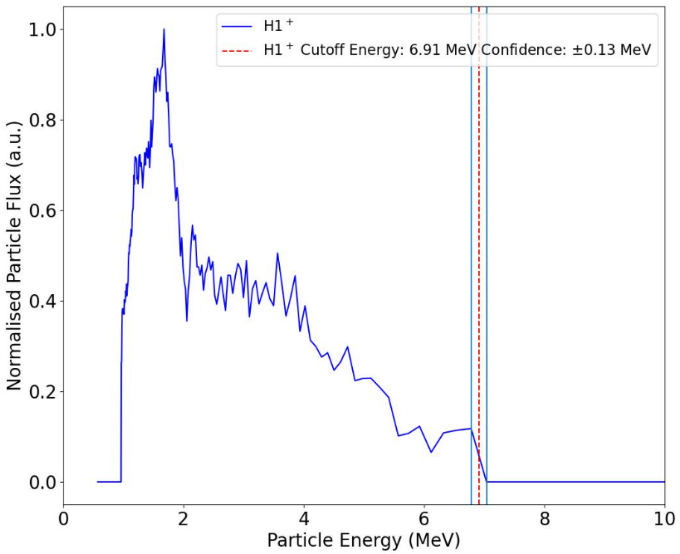
i) Proton maximum energy intensity scaling

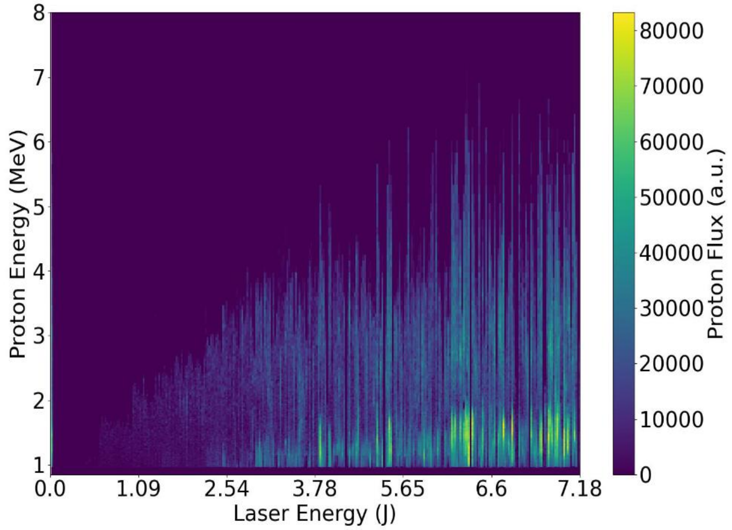
- Repeated scans of proton maximum energy (Ep Max) scaling with laser intensity, first measured on LhARA July 2023 exp, to test alterations to the laser system (laser energy, beam/spot quality, etc).
- Alterations to the laser are significantly influencing the scaling and thus the Ep Max we achieve.
- Initial testing of thinner targets is promising, showing increased Ep Max, however resulted in significantly more EMP issues.



ii) Proton spectral properties

- Example energy spectrum presented. Next step is to calibrate, to extract real particle numbers.
- Continued testing the stability of spectral properties. Measuring a high degree of variation at peak laser intensities.





Source Development Updates

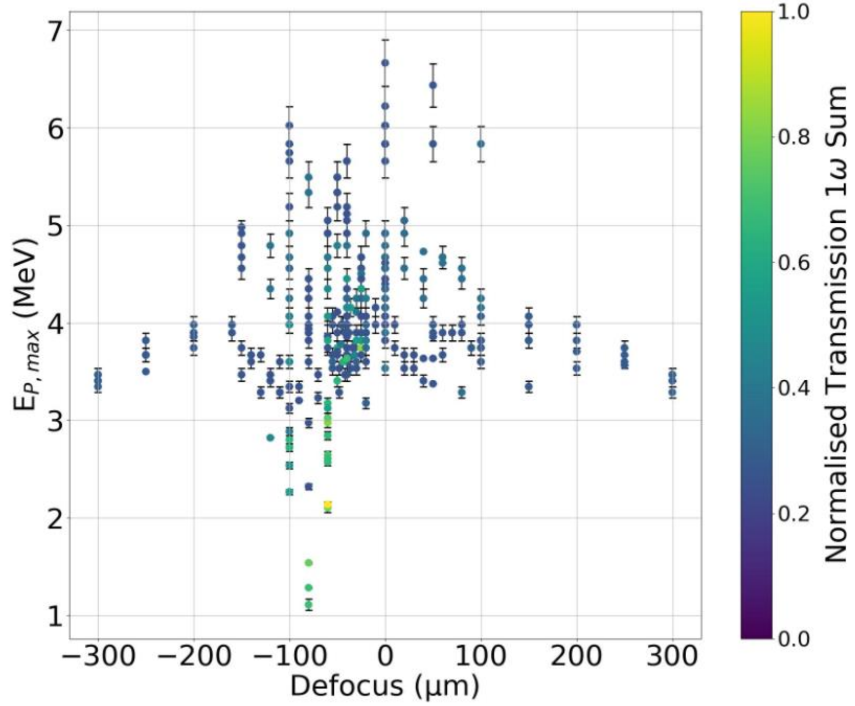
Potential source of non-ideal proton properties

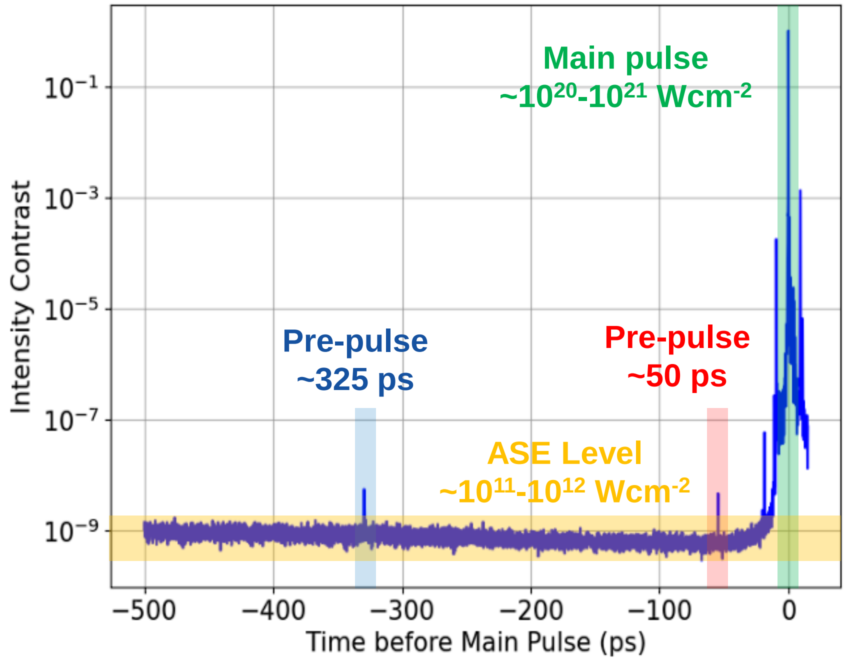
Measurables

- Measuring a significant portion of the laser pulse transmitted through the target plasma, up to 30%.
- Transmitted light should not be occurring for these target parameters, suggesting significant pre-expansion of target prior to main pulse.

Potential cause

- Through measurement of the laser temporal-intensity contrast, we have discovered a few potential ‘pre-pulses’ which may help explain our proton measurements.
- Laser staff have undertaken a program of work to identify the source of these and to potentially remove them over the coming months.

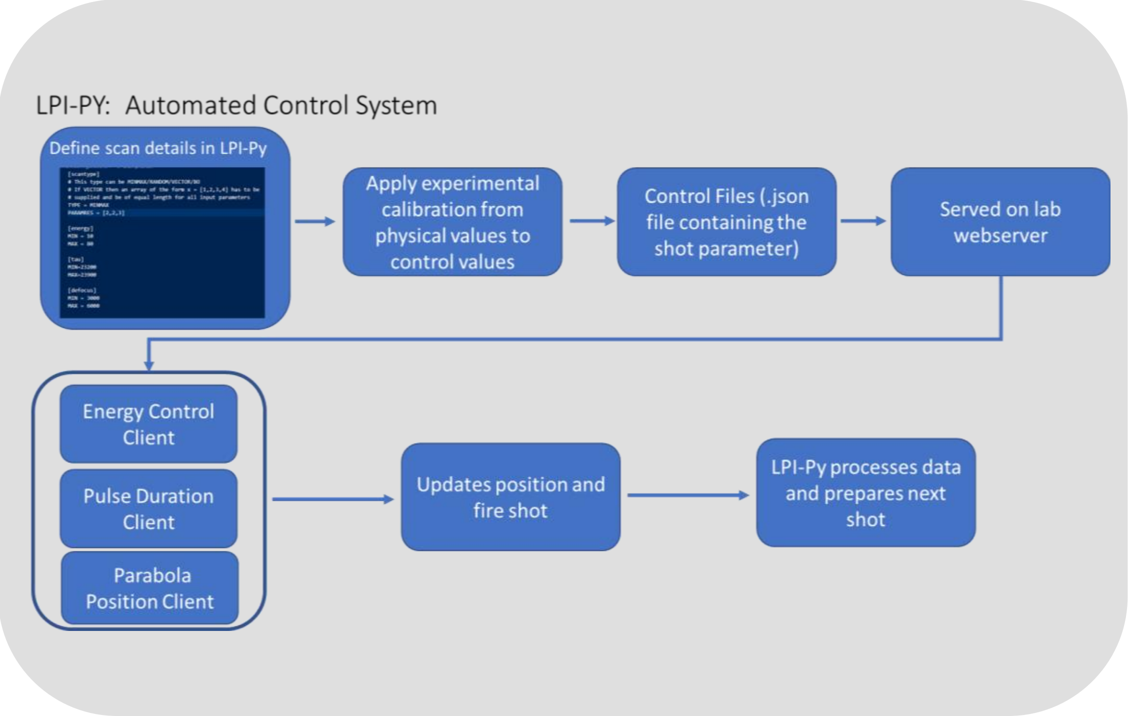




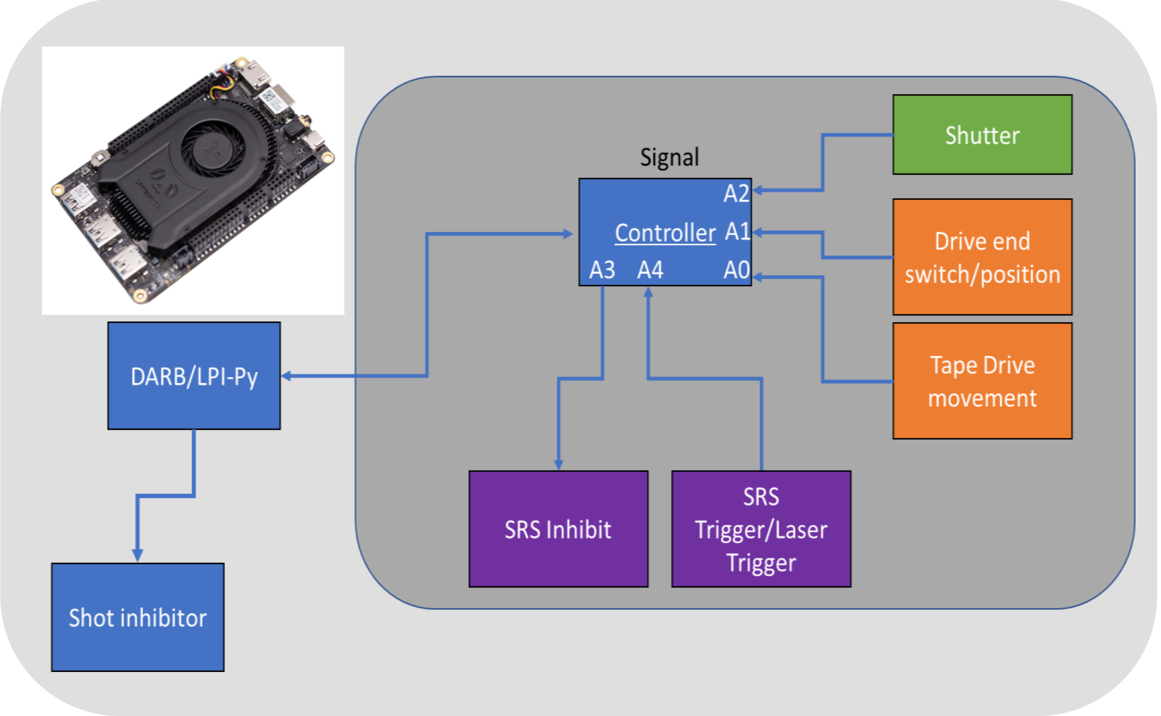
Data capture and high repetition rate operations

- New version of the DARB software successfully employed to capture and structure experimental data. This update increases data capture rates to 1 Hz and is now running stable manner.
- Continued the development of two new systems to i) automate parameter selection and ii) introduce a machine safety shutoff. These will significantly improve shot rate, time taken to repeat a data given scan, and data quality.

Automated Control System



Shot control system



Key Next Steps

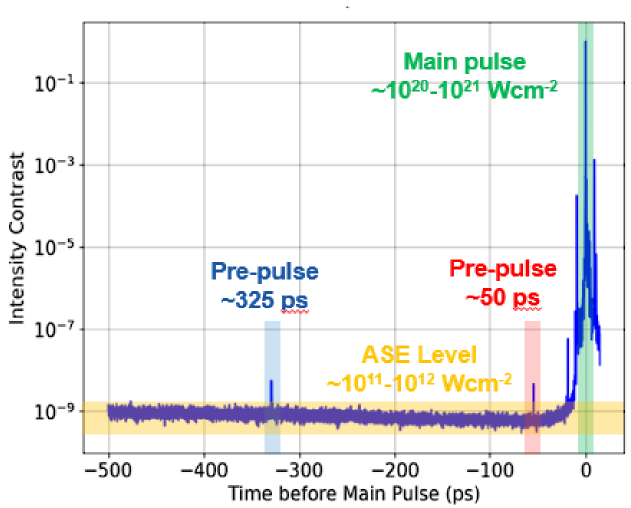
Roadmap to next beamtime (3 weeks in June)

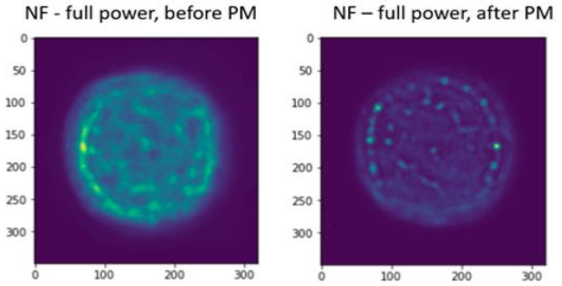
Aim: Investigate the proton source properties after improvements to the laser system.

1. Pre-pulse source investigation and potential removal.

2. Beam nearfield improvement by investigating amplifier pumping.

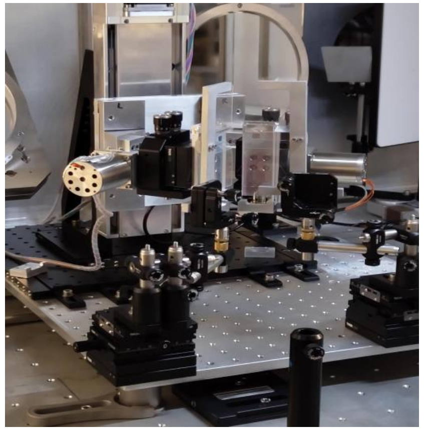
3. Reinstallation and commissioning of double plasma mirror system.





Additionally steps

- Installing EMP mitigation systems to targetry systems to facilitate thinner metal tapes.
- Finalise the particle number calibration of the Thomson parabola ion spectrometer.



Thank you for your attention

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