WP2: Update on first LhARA beamtime on SCAPA

Ross Gray

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20th September 2023

SCAPA Experiment Team….

University of Strathclyde

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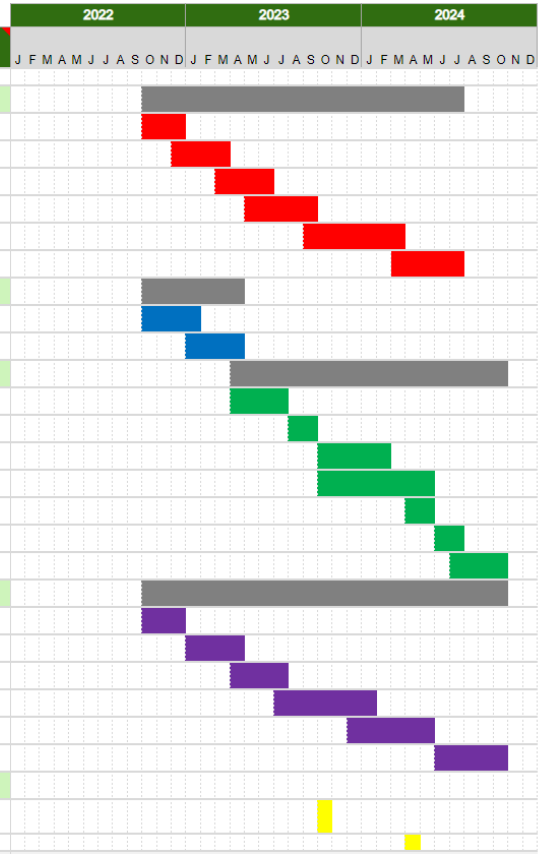
WP2 project plan…

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

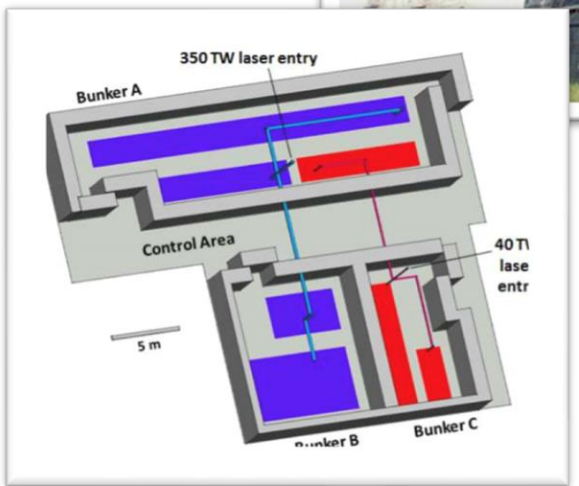


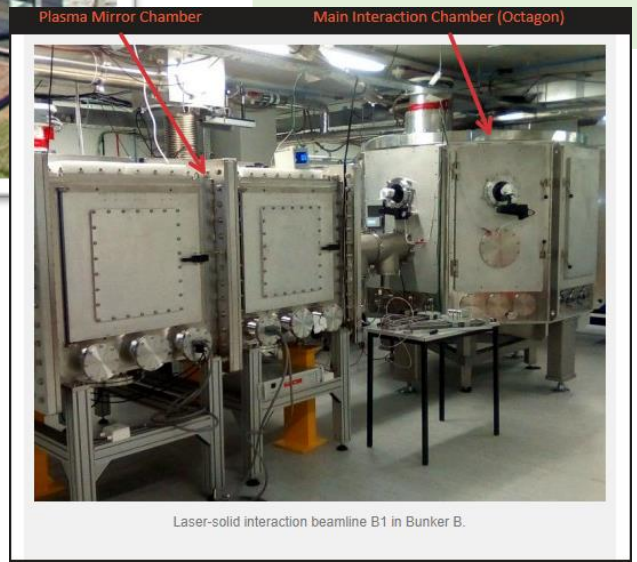
- Deliverables for the first two years are focused on early experiments and source benchmarking in simulations, as well as initial technology development in diagnostics and targetry.

- For the initial experiments we would ideally like to perform detailed, statistically significant parameter scans to establish and optimise the source performance.

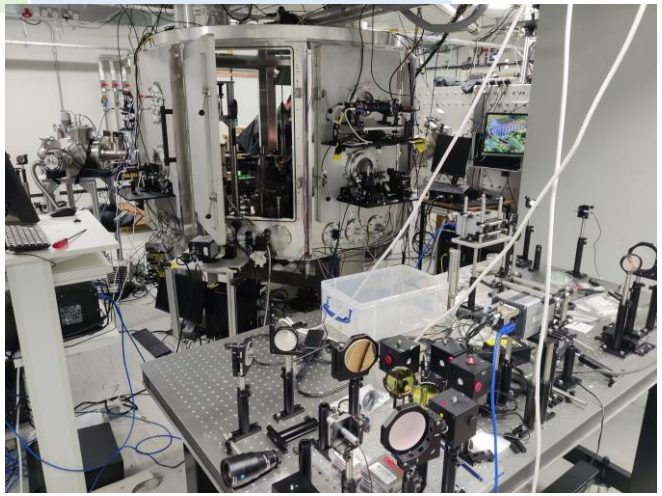
Scapa: Scottish Centre for the Application of Plasma-based Accelerators

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.



Developments in Targets, Diagnostics and Data Handling….

Diagnostics Development for SCAPA experiment

Ion Diagnostics –

- Online proton beam footprint monitor
- RCF Stack
- Thomson Parabola ion spectrometer

Optical Diagnostics –

- Specular reflection scatter screen (imaging 1w and 2w) and optical spectrometer
- Backscatter scatter screen (imaging 1w and 2w) and optical spectrometer
- Transmission scatter screen (imaging 1w and 2w) and optical spectrometer
- Transverse optical probe, operating in an interferometry configuration

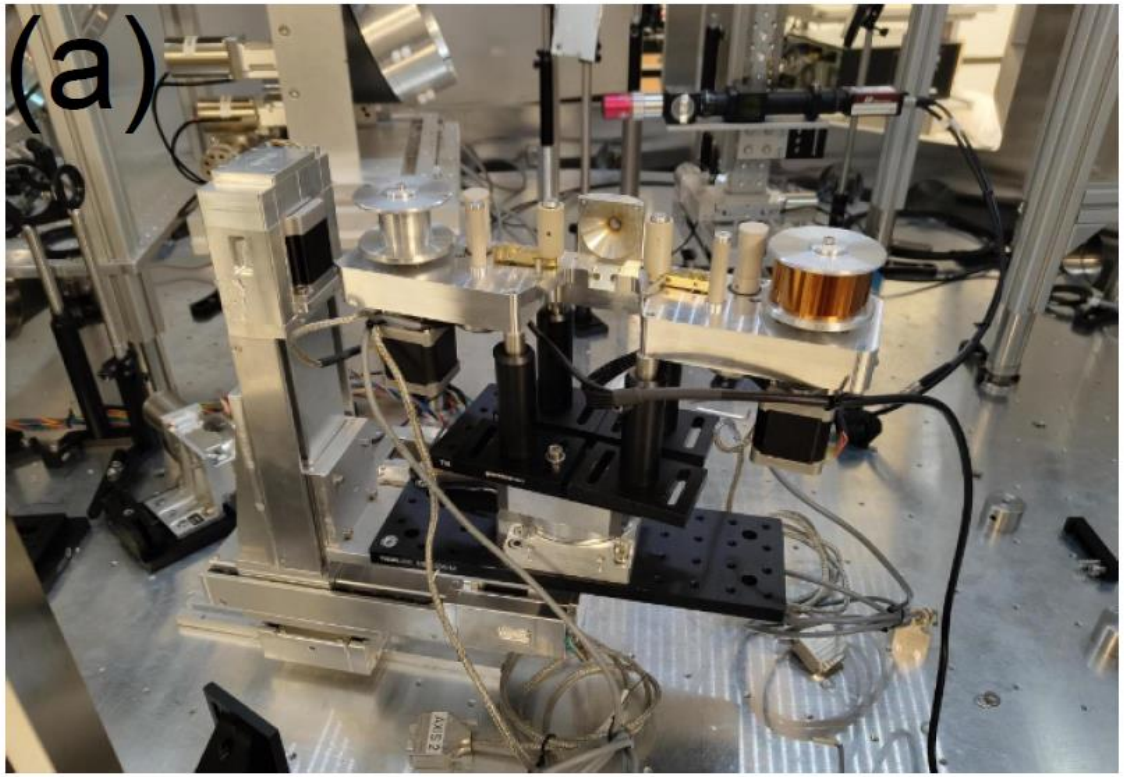
Electron Diagnostics –

- Lanex beam imager
- Compact electron spectrometer

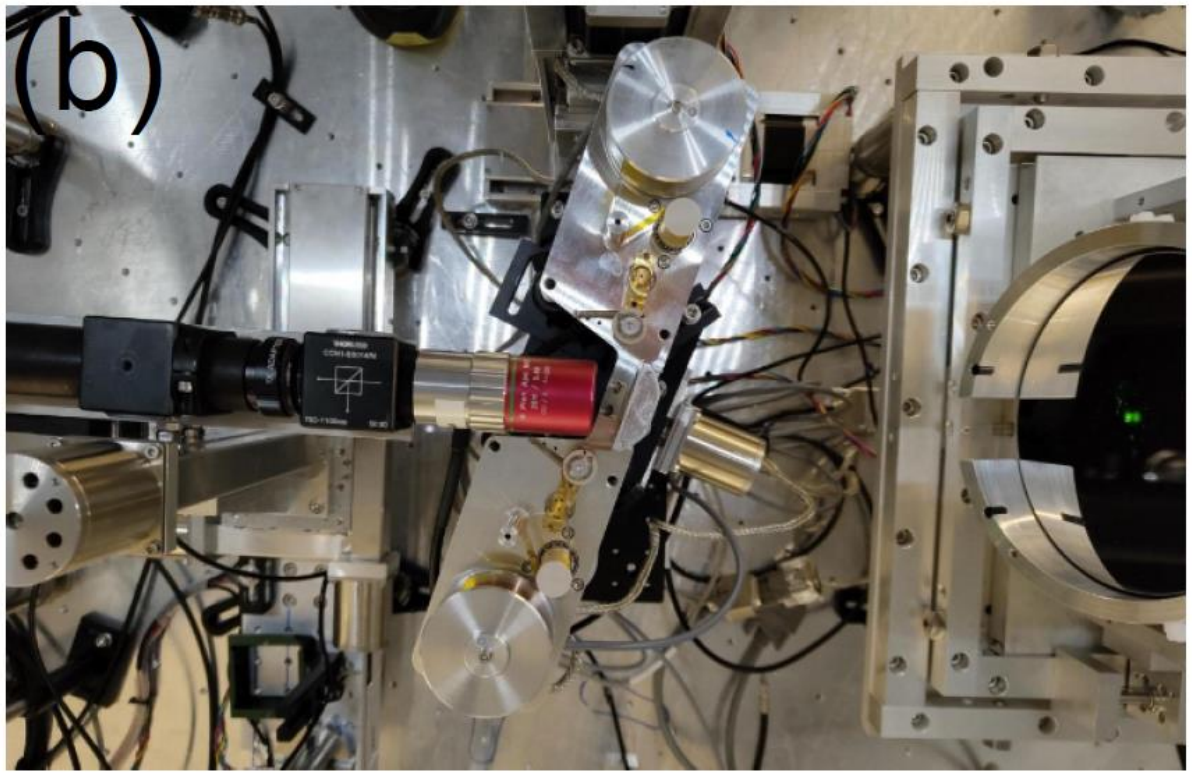
Debris Diagnostics–

- Witness plates (glass slides with section covered with Kapton tape, to be post-characterised by target fab (CLF))
- Witness optics (optical setup with a laser reflection from optics exposed to debris. Gives real time optic degradation measure.)

Wider tape drive mount for 35 degree angle of incidence…

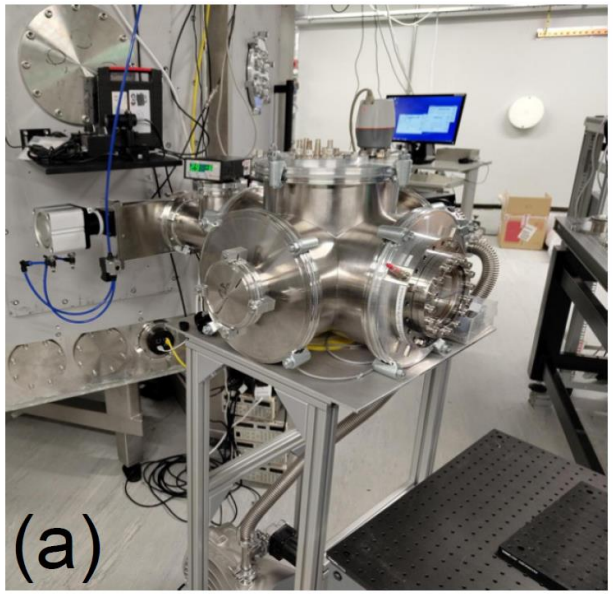


Rear view of Tape Drive

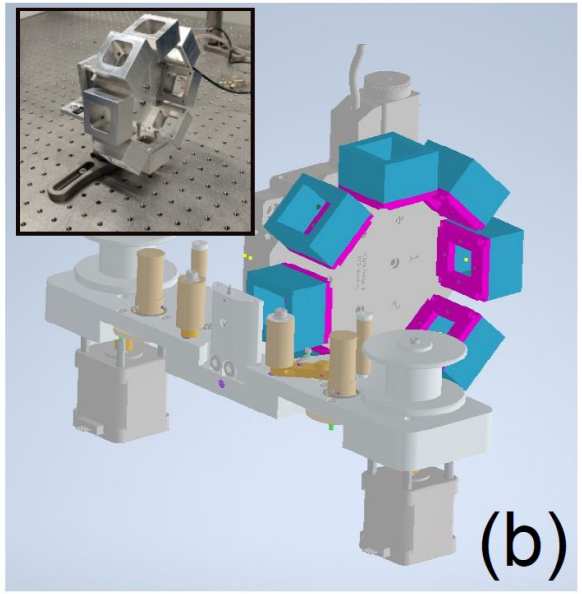


Top view of tape drive with focal spot camera in place

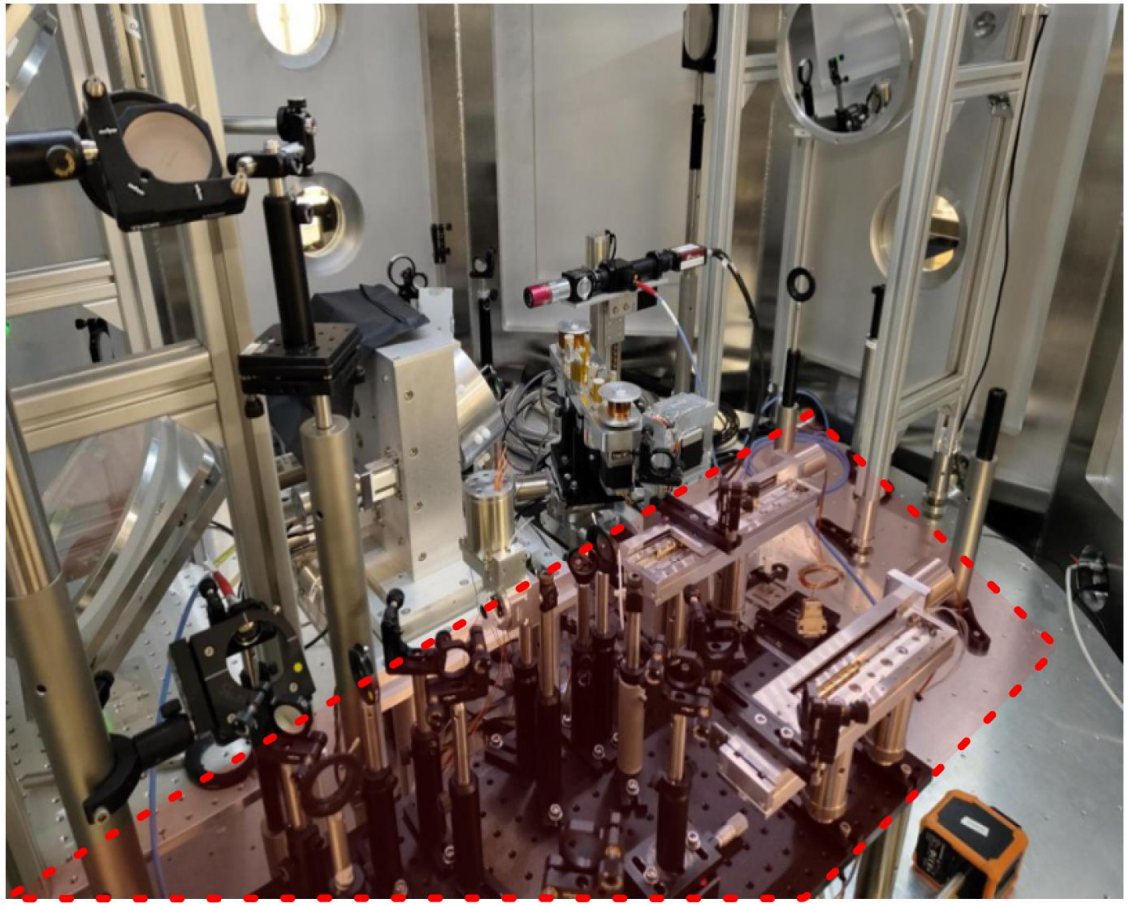
New ion and optical diagnostics….



Thomson Parabola Spectrometer Chamber

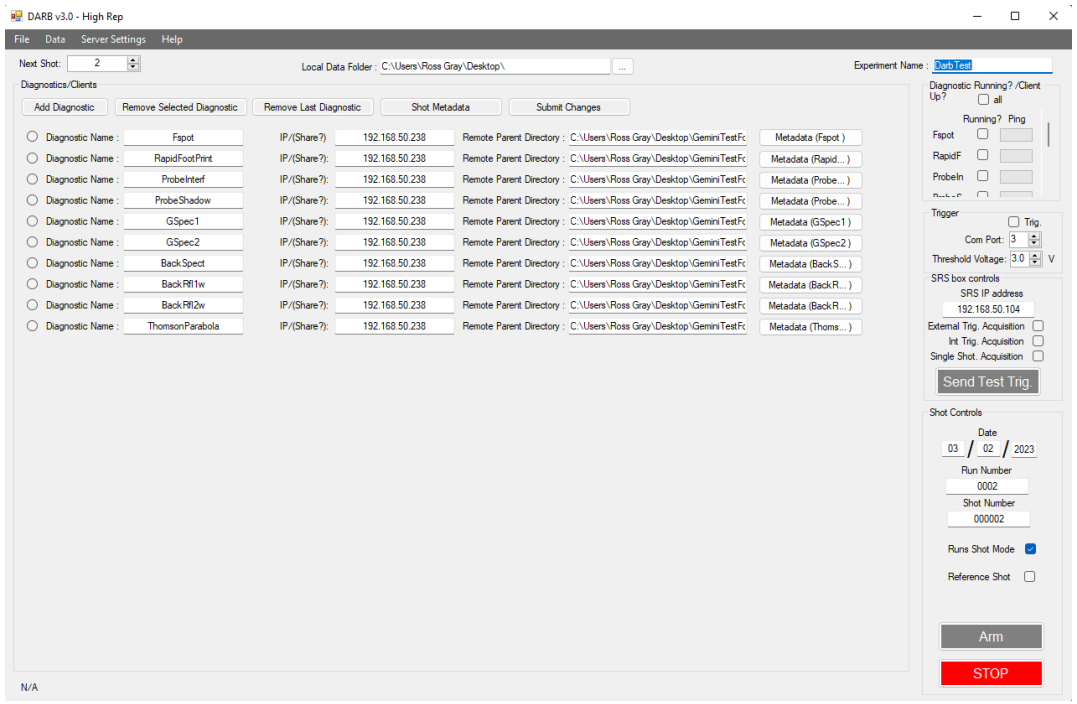


Multi-shot RCF wheel



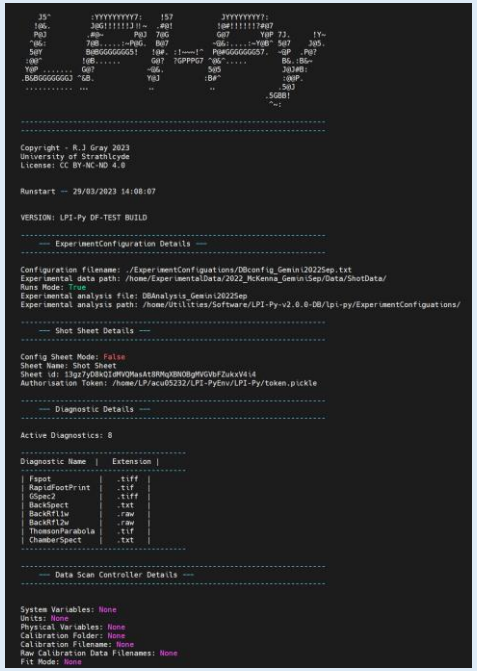
Combined prepulse and optical probe beamline

Data collection at Hz repetition rates – DARB V3.0



- Data collection system we developed at Strathclyde ~10 years go and have used on many different laser systems.
- Initially designed for high energy, low rep systems with a client-server model
- Complete rewrite of the backend and data transfer changed to “publisher-subscriber” model with data transfer that is asynchronous with shot.
- Up to 1 Hz data collection demonstrated on recent SCAPA run

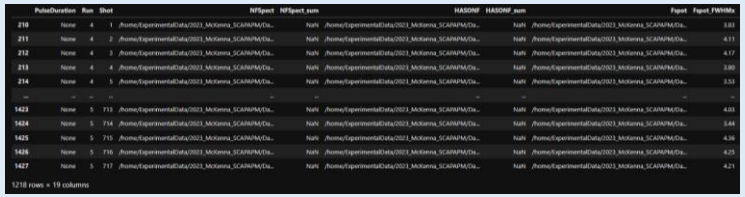
LPI-Py DB – Custom configurable analysis of experimental data and storage in a live database



- Configuration profile defined for a specific experiment
- Custom analysis class that make use of in-built fileloaders, analysis functions and calibrations

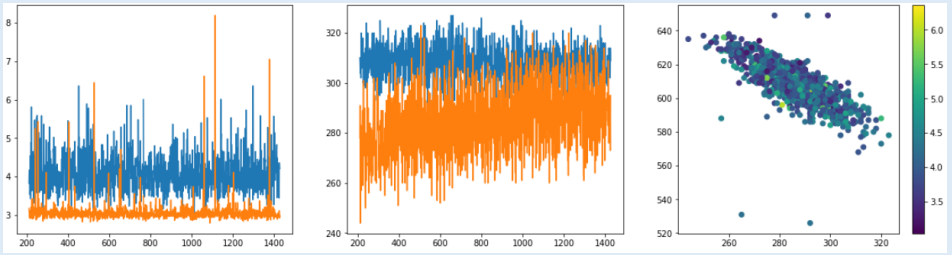
Actively updates on new data

- applies user-defined analysis class
- makes use of inbuilt file loaders, analysis functions and calibrations

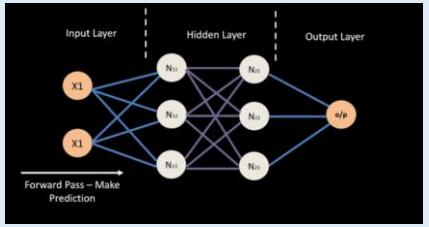


Pushes processed data to a live, searchable database

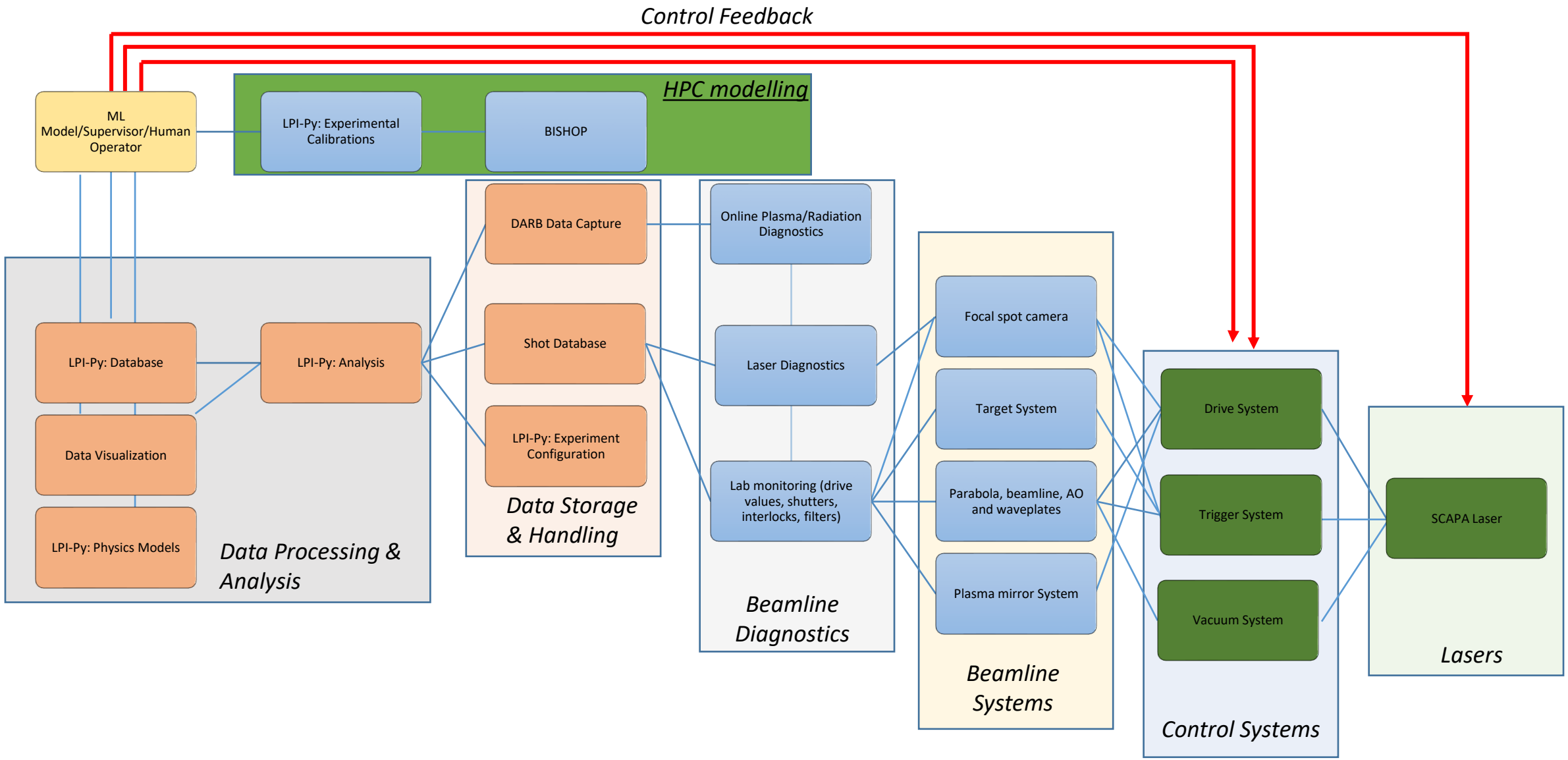
Data Visualisation



Model Training



Automated/Feedback driven data capture runs….



- Our ambition is to develop a highly integrated command and control system with high levels of automation

First results from the LhARA beamtime on SCAPA….

Objectives

Objective 1: *Ion acceleration characterisation*

- High resolution parameter scans: varying focal spot size, laser pulse energy and pulse length
- Characterisation of generated proton beam stability over a large number of shots, at high repetition rates

Objective 2: *Debris characterisation*

- Characterisation of generated debris from tape drive target system over several shots

Objective 3: *Diagnostic development*

- Testing of PROBIES Lanex detector lifetime over a series of fixed parameter shots

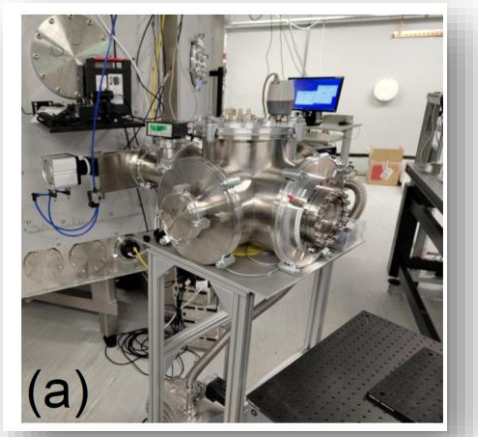
Outcomes:

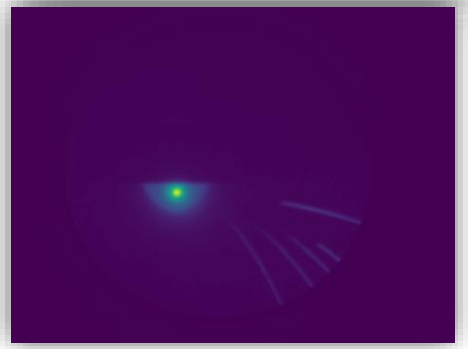
- Demonstration of ion source at 1Hz operation using tape drive configuration.
- >2000 shots, covering wide ranging data sets, varying key parameters related to source optimisation.
- Demonstration of both proton and carbon ion acceleration.
- Demonstration of data capture and live analysis at Hz repetition rates.

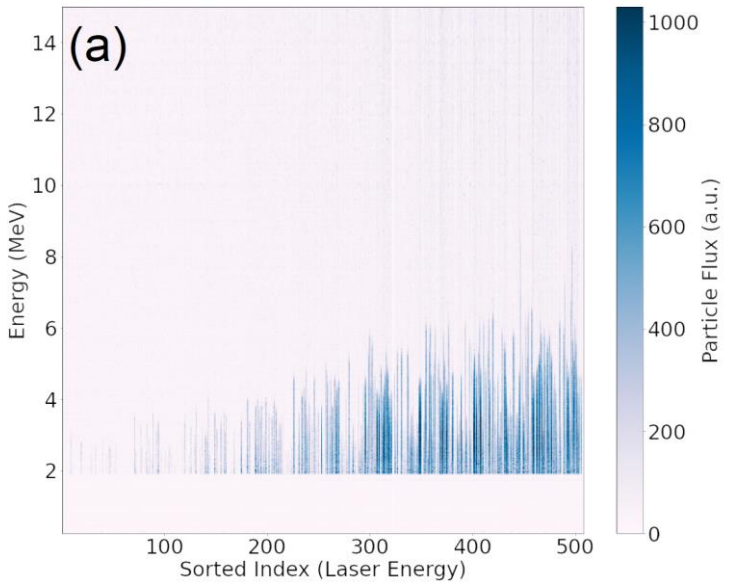
Issues:

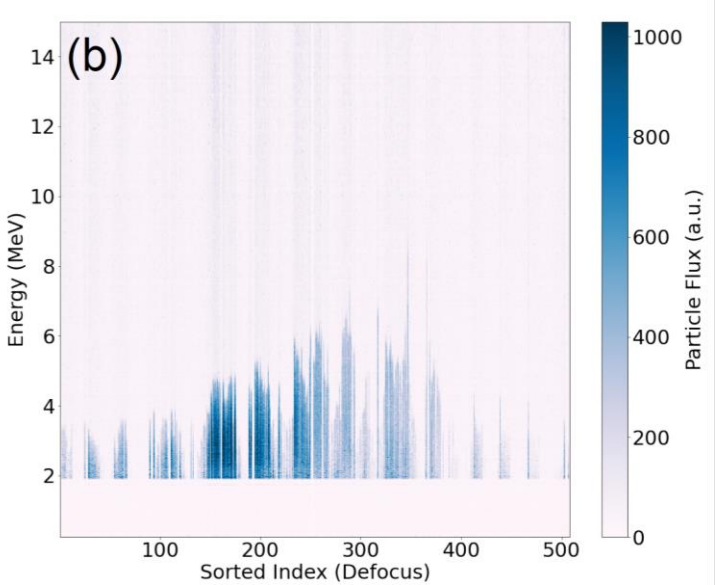
- Debris build up/ coating damage of F/1.5 OAP.
- Turbo film pellicle burning/20% loss in energy (see next slides).
- Maximum proton energy (~9 MeV) currently < 15 MeV but plans in place to push it higher

Laser energy, defocus and pulse duration parameter scans…



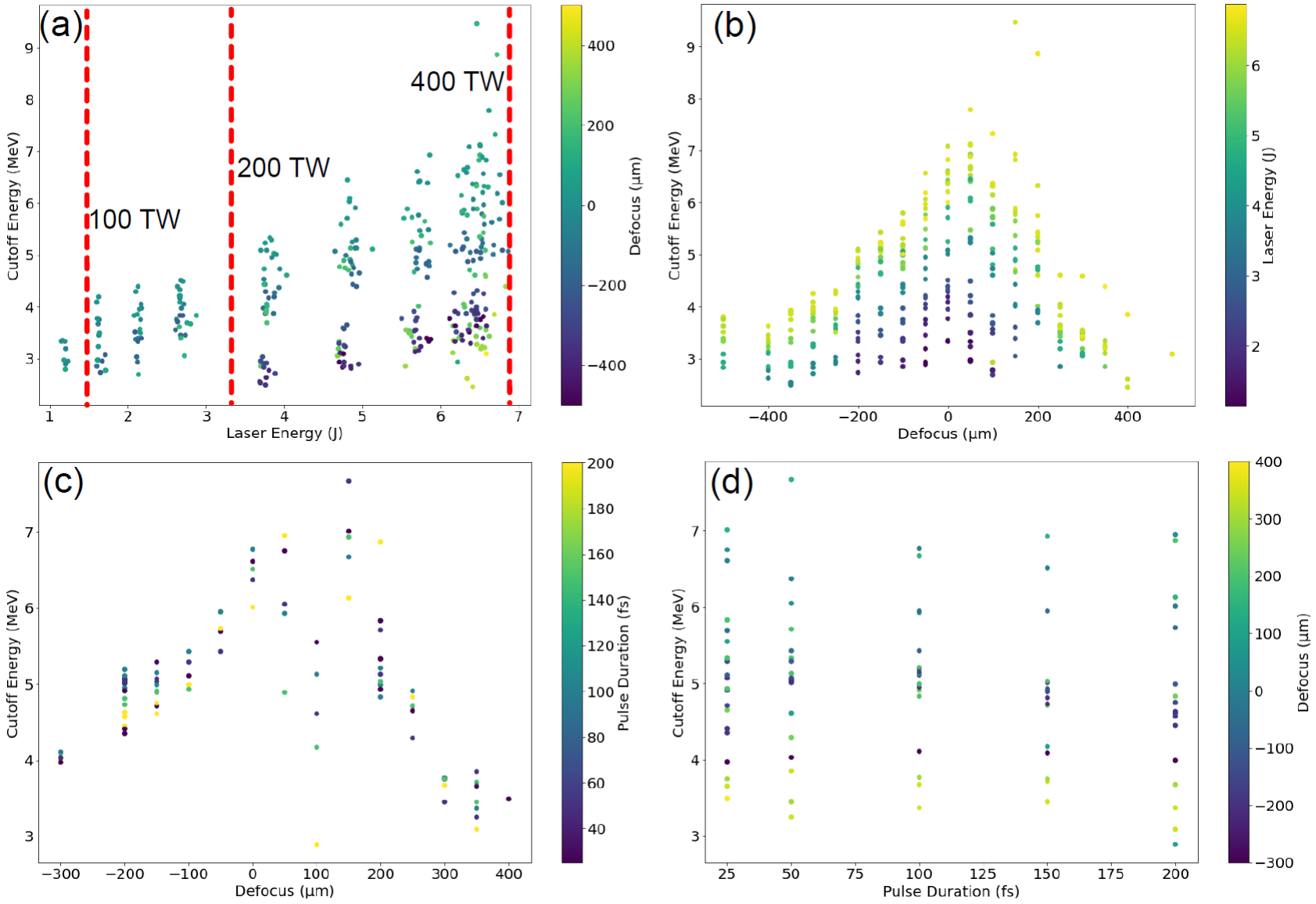






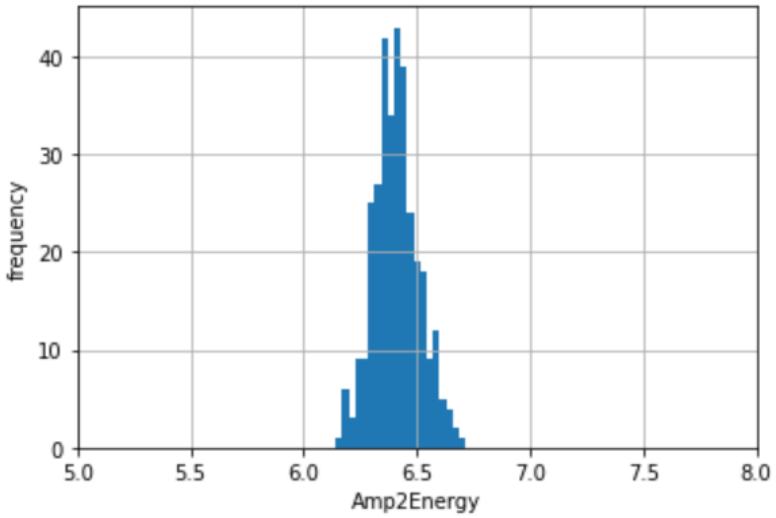
- The heatmaps show the proton spectrum as measured by the Thomson parabola ion spectrometer
- We also have extensive data for Carbon acceleration but prioritised analysis of protons for this report….
- **Maximum proton energy measured is ~9 MeV, currently < 15 MeV.**
- **<u>We have more optimisation to do in target thickness and preplasma scalength!</u>**

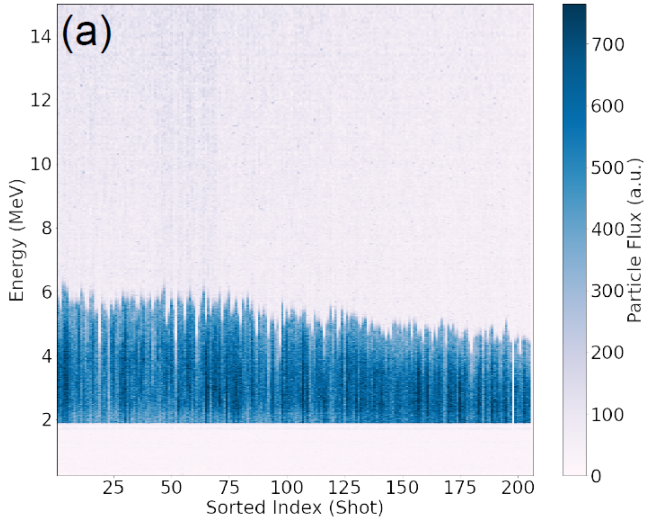
Proton Max Energy: Laser energy, defocus and pulse duration parameter scans…

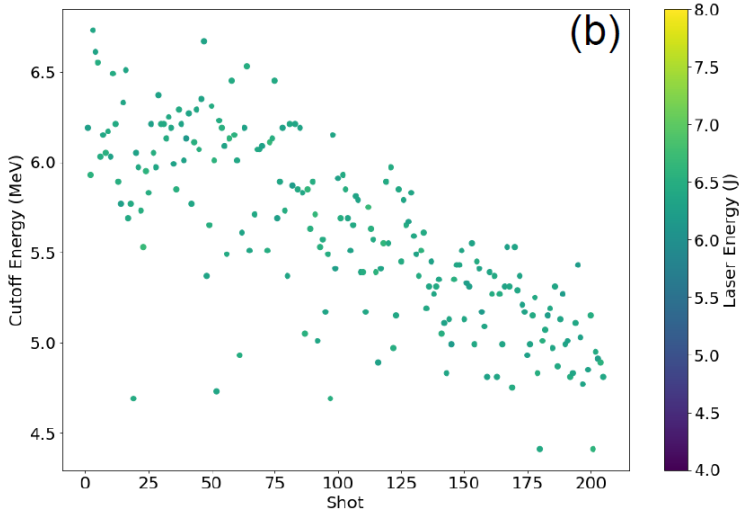


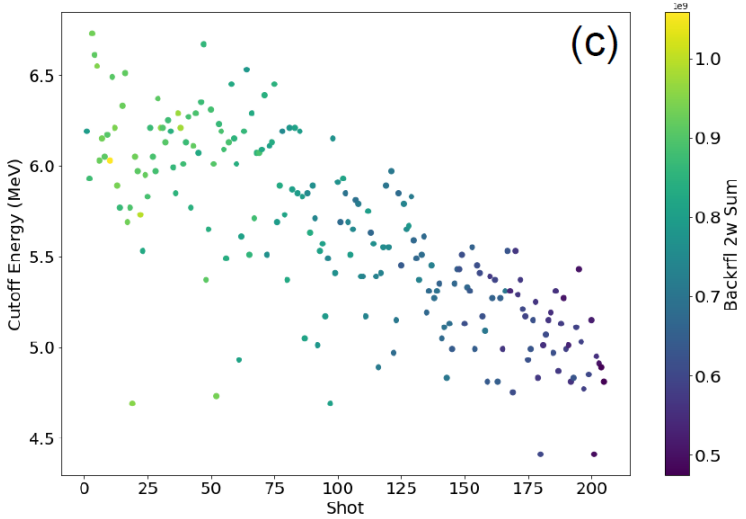
- We confirm previously demonstrated strong dependency with laser energy and defocus
- Proton max energy dependence on pulse duration is much weaker
- The laser baseline spec should prioritise maximising the available laser energy and focus….even at the cost of pulse duration
- We expect to push these energies further with preplasma and target thickness optimisation

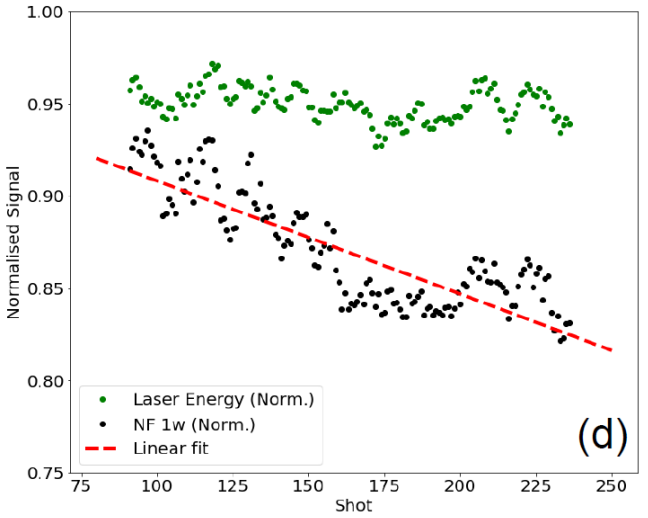
Proton max energy stability……and a problem with the pellicle…



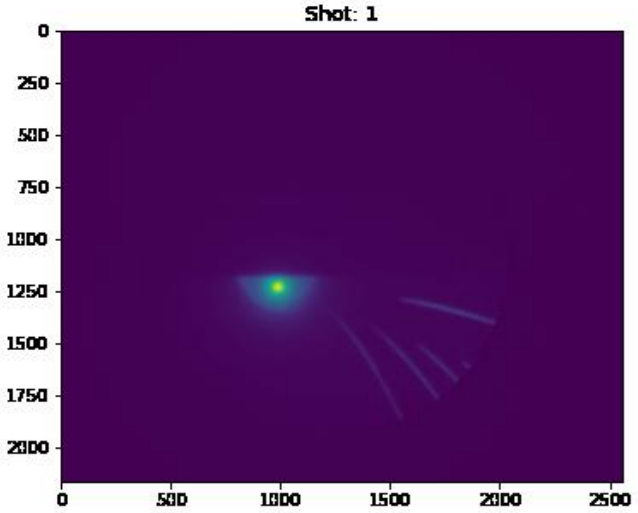




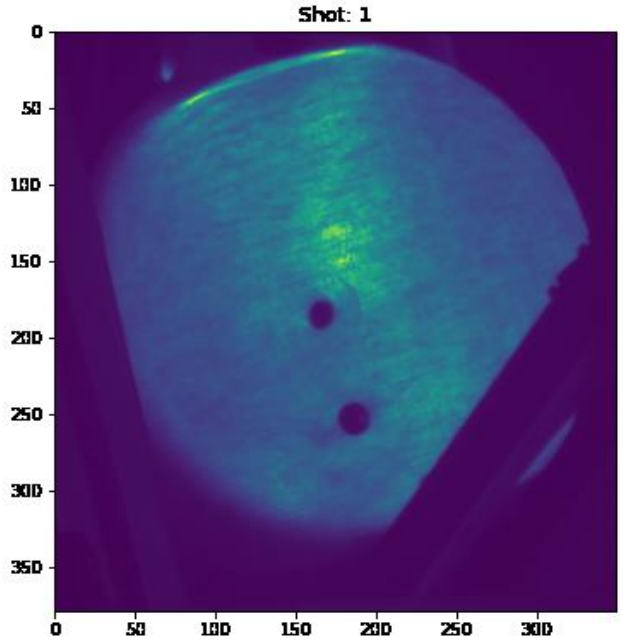




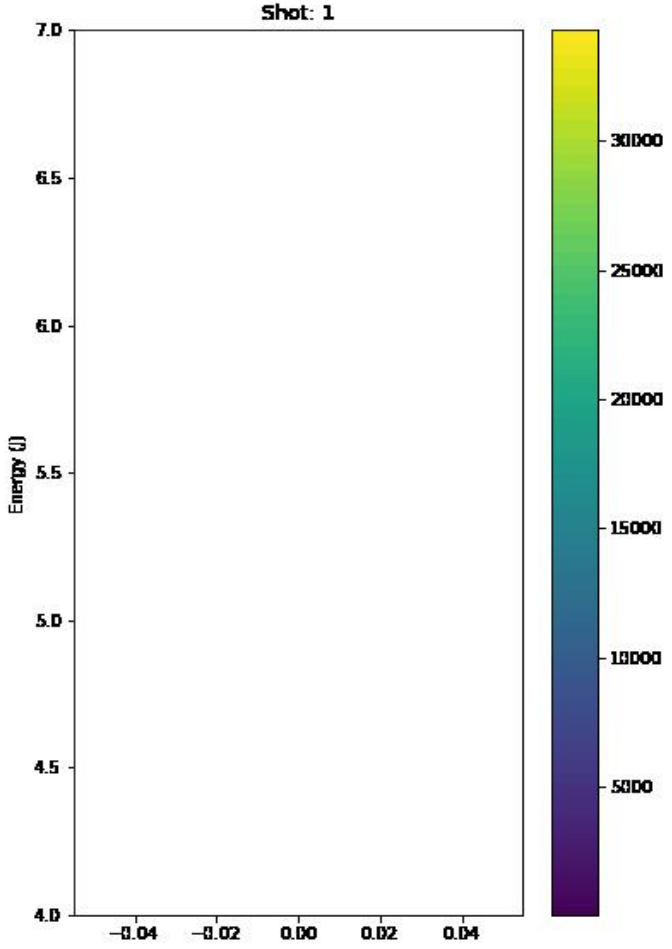
Proton max energy stability……and a problem with the pellicle…



Thomson Parabola Spectrometer

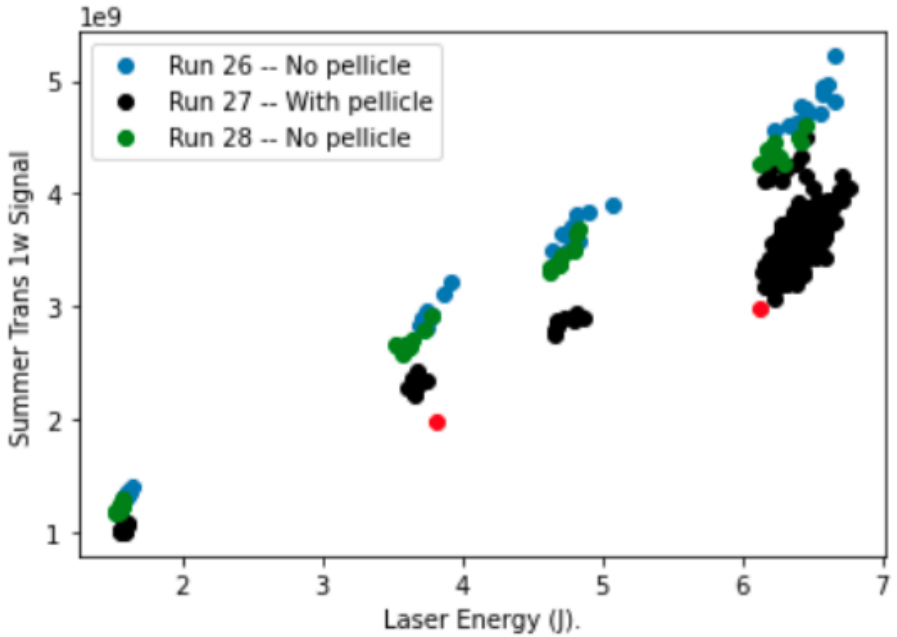


Back Scatter (2ω) NF



Laser Energy

Proton max energy stability……and a problem with the pellicle…



- We are observing attenuation of the of the incoming beam by the pellicle and rapid burning over 100 full power shots
- We have an alternative material which is AR coated and should survive much longer (although considerably more expensive)
- We are aiming to investigate this during commissioning work in November 2023

July SCAPA experiment…main lessons

Issue	Action
1. Maximum proton energy measured up to 9 MeV (2x since last beamtime)	We need > 15 MeV. Thinner targets and contrast control required
2. High repetition rate (1 Hz +) now possible but long term operation challenging	We need to investigate the pellicle and beamline damage issues
3. Tape drive is now operating well but a new (even wider) design would help alignment	Further updates to the base plate with the CLF
4. Laser contrast control required	Further development of plasma mirror and prepulser beamline
5. The probies detector needs further development and testing for our proton energies/flux	Calibration and testing of various scintillators at Birmingham accelerator will help (due in November).

Upcoming Beamtime……Scheduling

SCAPA

- Further test runs on the pellicle and plasma mirror system. Alongside further development on probe and preheater. This is likely in November.

- W/B 15th January is scheduled for the next LhARA run

SCAPA Experiment Team….

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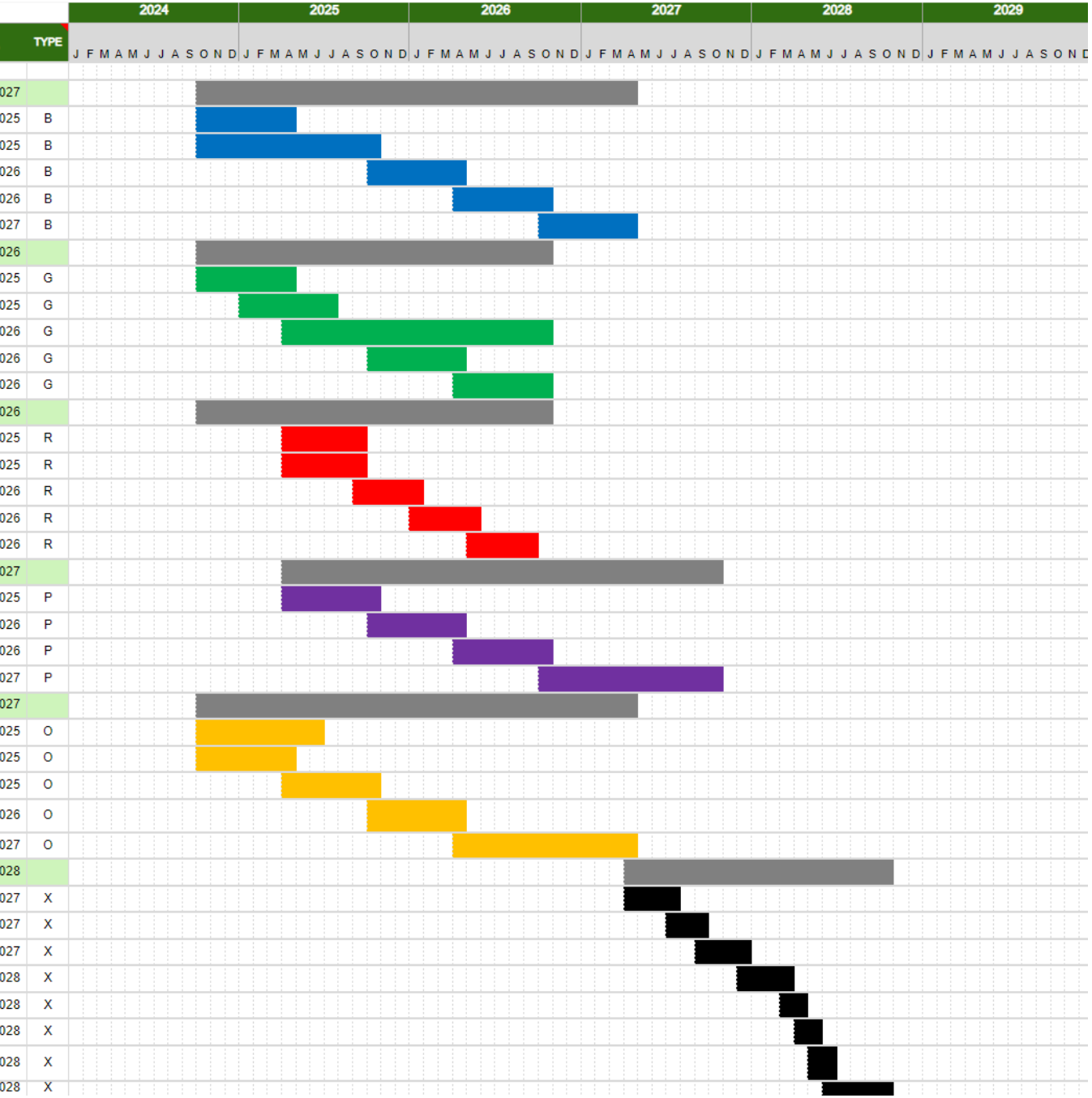
PA2: PoP experiment in SCAPA..?

Ross Gray

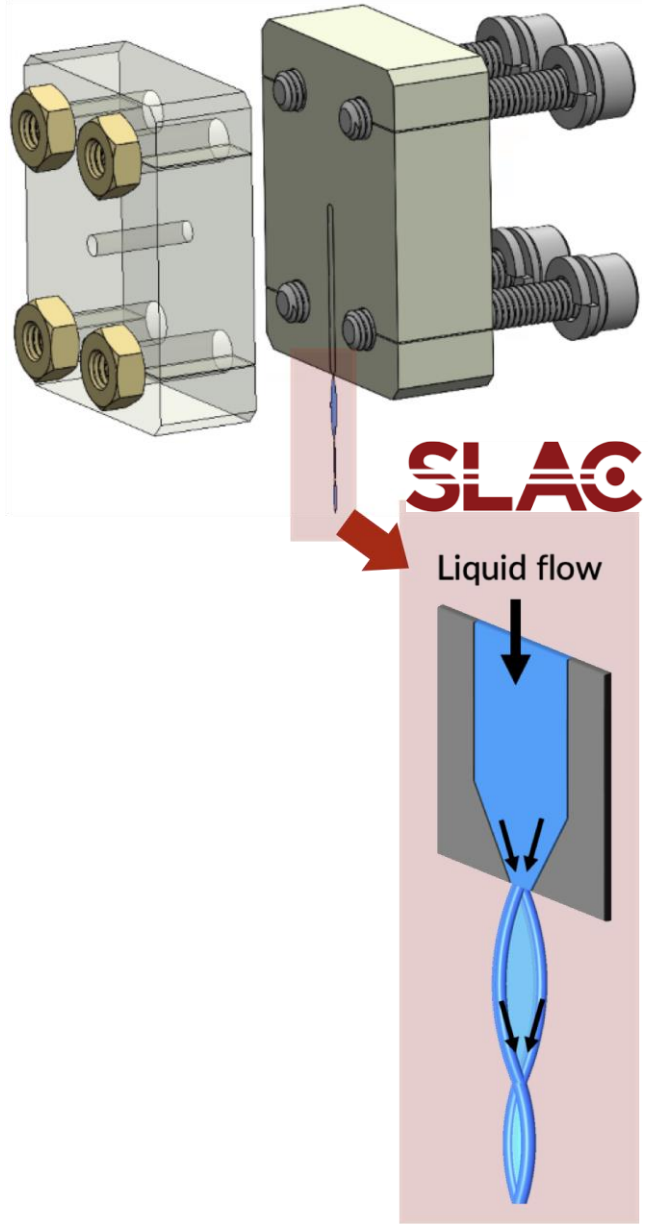
University of Strathclyde, Glasgow, UK

20th September 2023

TASK DESCRIPTION	START	END	TYPE
O1 - Diagnostic and hardware development	01/10/2024	01/04/2027	
Construction and installation of new source vacuum chamber at Imperial	01/10/2024	01/04/2025	B
Design and construction of ion diagnostics (profiler, TOF, TP)	01/10/2024	01/10/2025	B
Construction of laser spatial feedback diagnostics	01/10/2025	01/04/2026	B
Construction of laser temporal feedback diagnostics	01/04/2026	01/10/2026	B
Testing and control of integrated diagnostic platform at 5 Hz	01/10/2026	01/04/2027	B
O2 -Novel targetry development	01/10/2024	01/10/2026	
Target test vacuum chamber at CLF design and construction	01/10/2024	01/04/2025	G
Target characteristation diagnostic design and construction	01/01/2025	01/07/2025	G
Liquid jet development for high vacuum use	01/04/2025	01/10/2026	G
Hydro and kinetic modelling of water jet target for LhARA beamline	01/10/2025	01/04/2026	G
Planning for liquid jet integration into laser ion source chamber	01/04/2026	01/10/2026	G
O3 - Heavy ion source development	01/10/2024	01/10/2026	
Investigate optimal routes to heavy ion control via PIC simulations	01/04/2025	01/09/2025	R
Design and contruction of 2D heavy ion profiler	01/04/2025	01/09/2025	R
Testing of contaminant removal for tape targets at high repetition	01/09/2025	01/01/2026	R
Investigation of heavy ion generation using cleaned tape target	01/01/2026	01/05/2026	R
Water jet liquid changes for heavy ion production....	01/05/2026	01/09/2026	R
O4 - High repetition rate source operation development	01/04/2025	01/10/2027	
Diagnostic testing at IC for high repetition operation	01/04/2025	01/10/2025	P
Experimental study on debris capture and mitigation from tape target	01/10/2025	01/04/2026	P
Implementation and testing of ion source using water jet at IC	01/04/2026	01/10/2026	P
Testing of automated feedback and optimisation of the laser ion source	01/10/2026	01/10/2027	P
O5 - LhARA source demonstration experiments	01/10/2024	01/04/2027	
Investigate optimal routes to source control via PIC simulations	01/10/2024	01/06/2025	O
Investigation of laser source optimisation using prepulser density control	01/10/2024	01/04/2025	O
Experimental optimisation of laser-energy coupling into ion source	01/04/2025	01/10/2025	O
Study on ion spectral shaping by control of laser temporal profile	01/10/2025	01/04/2026	O
Integration of optimised diagnostics and laser control into ion source	01/04/2026	01/04/2027	O
O6 - High Repetition Rate Operations at Full Specification	01/04/2027	01/10/2028	
Experiment Planning, Design and Preparation	01/04/2027	01/07/2027	X
SCAPA experiment demonstrating operation of ion source at 5Hz in burst mod	01/07/2027	01/09/2027	X
Data Processing and Analysis	01/09/2027	01/12/2027	X
Experiment Planning, Design and Preparation	01/12/2027	01/03/2028	X
Continous 1 hour operation at 5 Hz	01/03/2028	01/04/2028	X
Continous 1 hour operation with feedback mode	01/04/2028	01/05/2028	X
Demonstration of 10 Hz continous operation using 10 Hz trigger mode and 5Hz laser operations	01/05/2028	01/06/2028	X
Data Processing and Analysis	01/06/2028	01/10/2028	X

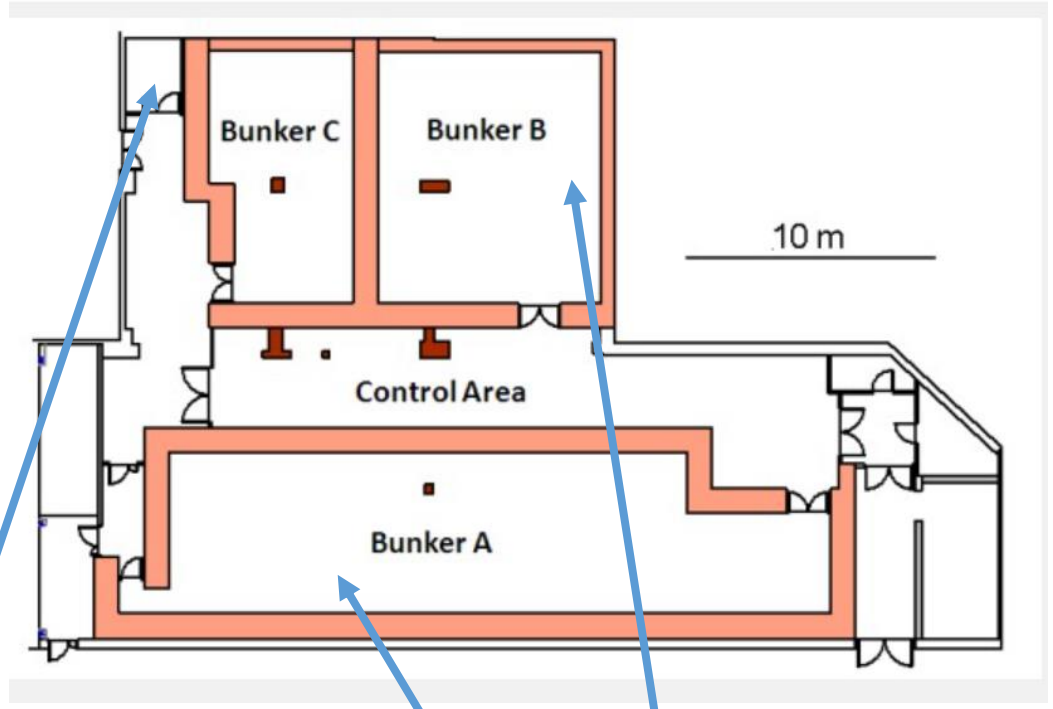


Liquid sheets targets for high-rep, low-debris ion acceleration



- High-purity mm-scale liquid sheet with variable thickness down to 200 nm, compatible with kHz operation (Morrison et al., NJP (2018)) and Joule-class lasers (Treffert et al., APL (2022)).
- Vacuum conditions challenging but may provide unforeseen benefits in terms of shot-to-shot stability and proton flux.

Ground Floor Labs

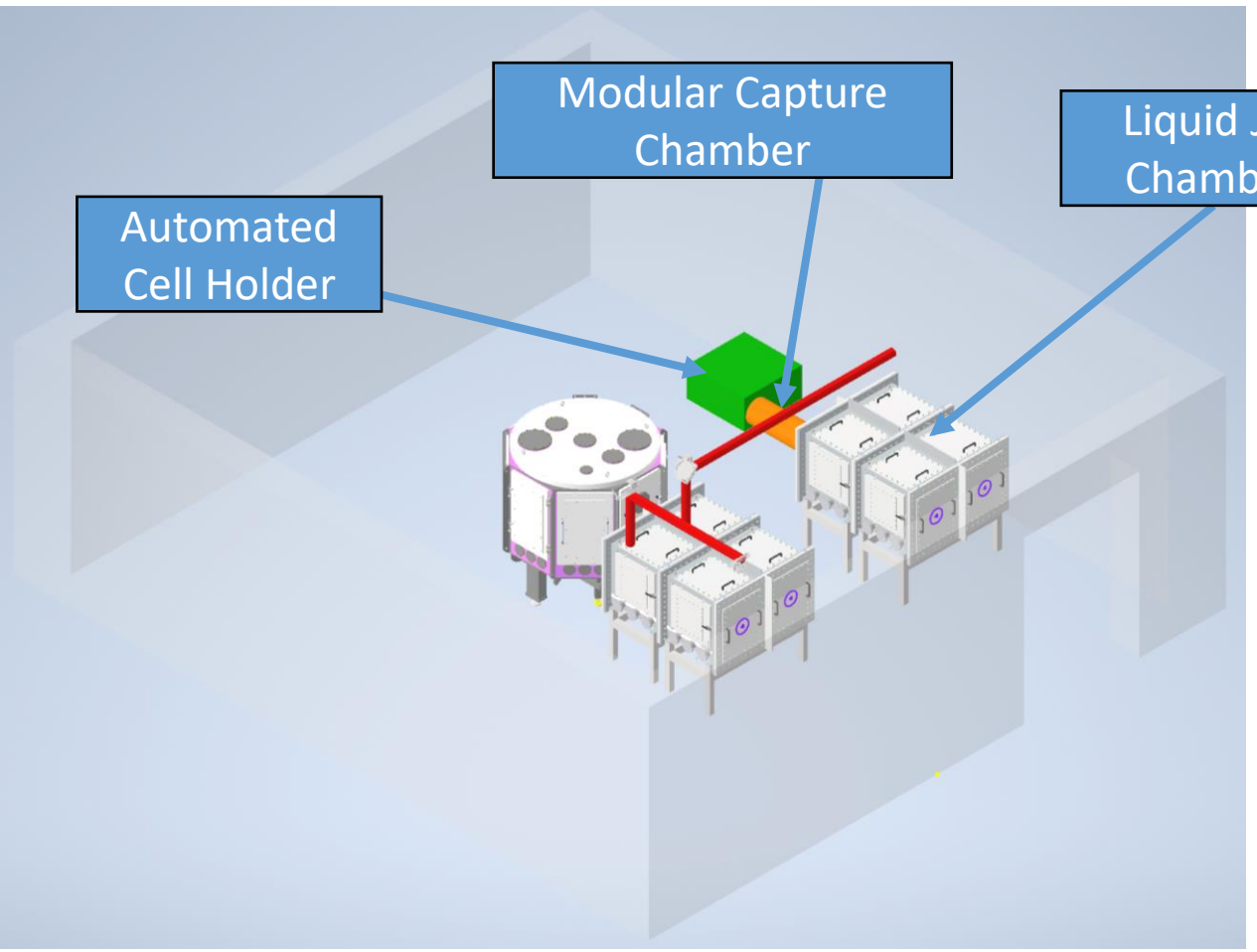


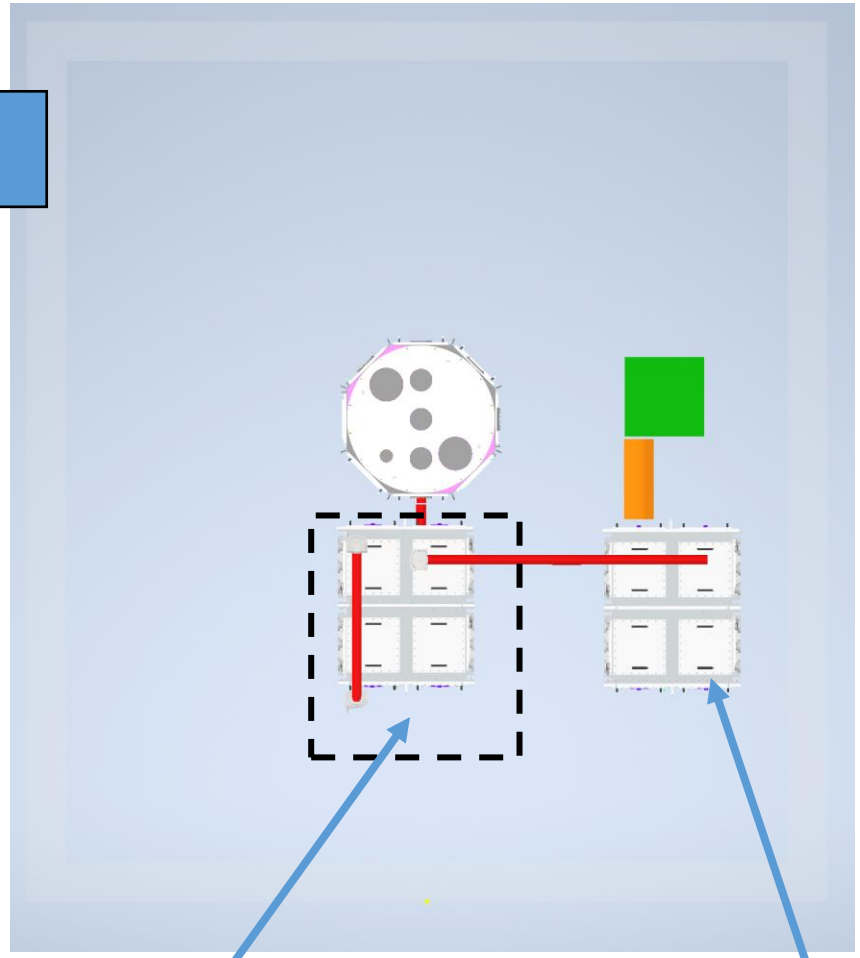
Authorised animal housing during the day, overnight storage in SIPBS

Ion/gamma Source Bunker

Electron/gamma Source Bunker

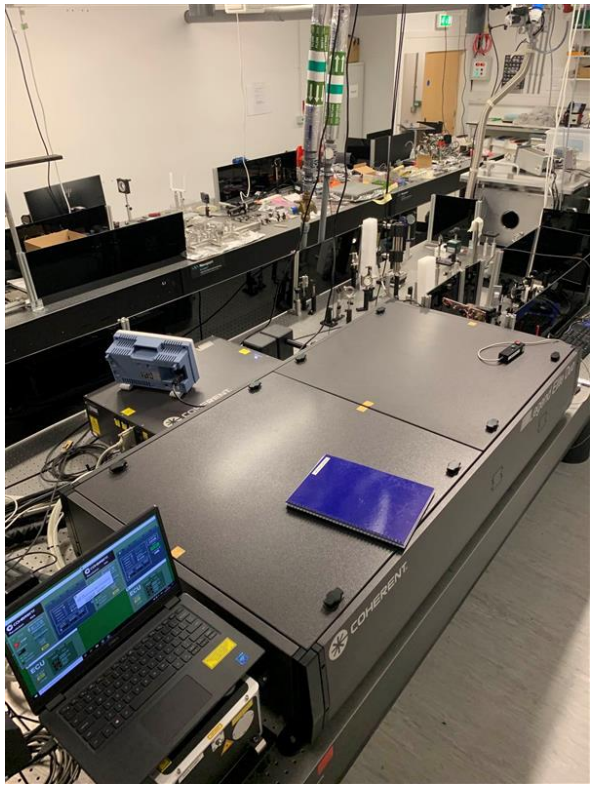
Proof of Principle Experiment Concept in Bunker B





1st Floor Labs

Bio prep room for off-line cell work



kHz lab for high-repetition rate target testing

Date: 31-Aug-23 Issue 3

Project	**LhARA**	***Laser-hybrid Accelerator for Radiobiological Applications***					
Work package	WPX	**Proof of principle: Integration and Biology**					
Manager	WPM	*N. Dover, R. Gray, C. Palmer*				***FTE pa***	***130.00***
						PhD student	85.00
Years		**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Total**
Flag		Fraction	Fraction	Fraction	Fraction	Fraction	Fraction
Task	***Task 1***						
Institute	**Strathclyde Physics**						
Staff	Strathclyde-Phys-PDRA-1			1.00	1.00	1.00	3.00
Staff	Strathclyde-Phys-Stf-1			0.10	0.10	0.10	0.30
Staff	Strathclyde-Phys-Tech-1			0.10	0.10	0.10	0.30
Staff	Strathclyde-Phys-PG-1						
RiskMitigationStaff	**Risk mitigation effort**						
EndStaff	**Staff totals**			**1.20**	**1.20**	**1.20**	3.60
							468.00
NonStaffHd	**Non staff**	£k	£k	£k	£k	£k	£k
Task	***Task 1***						
Equipment	Source Chamber			80.00			80.00
Equipment	Beamline optics			40.00			40.00
Equipment	Beamline drive system and controllers			40.00			40.00
Equipment	Vacuum pumps, flanges, controllers			30.00			30.00
Equipment	Gate valves			15.00			15.00
Equipment	Parabola			20.00			20.00
Equipment	Windows			15.00			15.00
Equipment	Capture System				50.00		50.00
Equipment	Automated Cell Sample holder				50.00		50.00
EquipEnd	Sub-total			240.00	100.00		340.00
TotalEquip	**Equipment total**			**240.00**	**100.00**		**340.00**
Consume	Consumables (split Imp/Strath/CLF)			30.00	30.00	30.00	90.00
OtherNonStaff	SCAPA Access (Strath)			100.00	100.00	100.00	300.00
Travel	Travel for collaboration meetings/conferences (split all)						
OtherNonStaff	Costs for domestic travel to beamtime at Strathclyde/Imperial (split Imp/Strath/QUB))			7.00	15.00	15.00	37.00
NonStaffEnd	**Total non-staff costs**			**377.00**	**245.00**	**145.00**	**767.00**
	Non-staff costs include VAT but not inflation.					TOTAL	1235.00