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PoPLaR Meeting @ Strathclyde

Update on proton source capabilities and beamline design in SCAPA Bunker B

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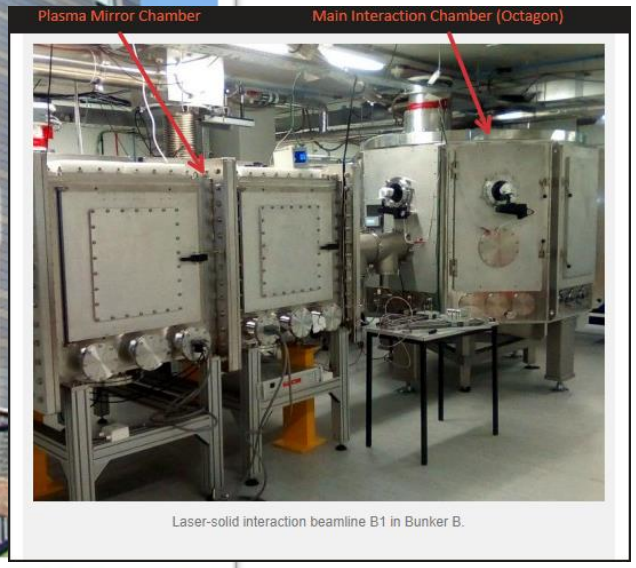
SCAPA: Scottish Centre for the Application of Plasma-based Accelerators

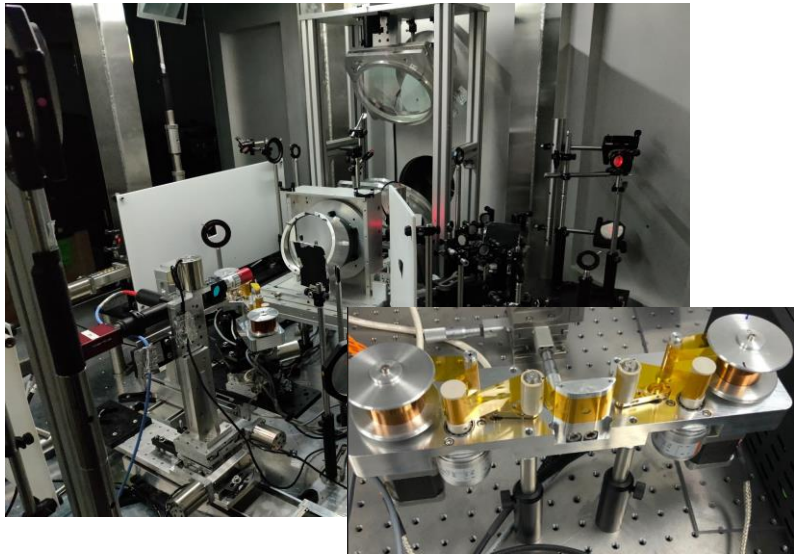
- Research is focused on the development and application of laser-driven particle acceleration.

- Can deliver high proton numbers, within the MeV energy range, at Hz level reception rate.

Parameters	
Peak Power	*≥350 TW*
FWHM pulse duration	*≤25 fs*
Energy per pulse (on target)	*up to 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*

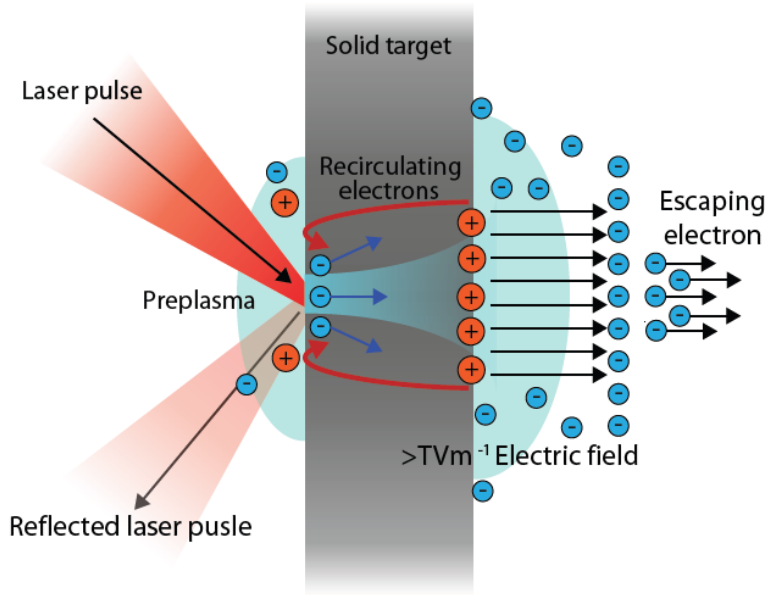


Laser-solid interaction beamline B1 in Bunker B.



Mechanism for laser-driven ion acceleration

Target Normal Sheath Acceleration (TNSA)



Laser energy absorbed producing large population of hot electrons

↓

Hot electrons injected and propagate through the target

↓

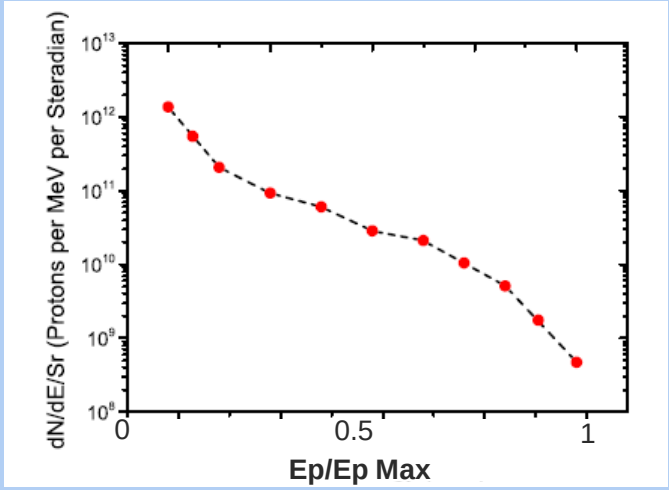
Generates strong (~TV/m) electrostatic sheath fields at target rear

↓

Drives acceleration of high energy protons

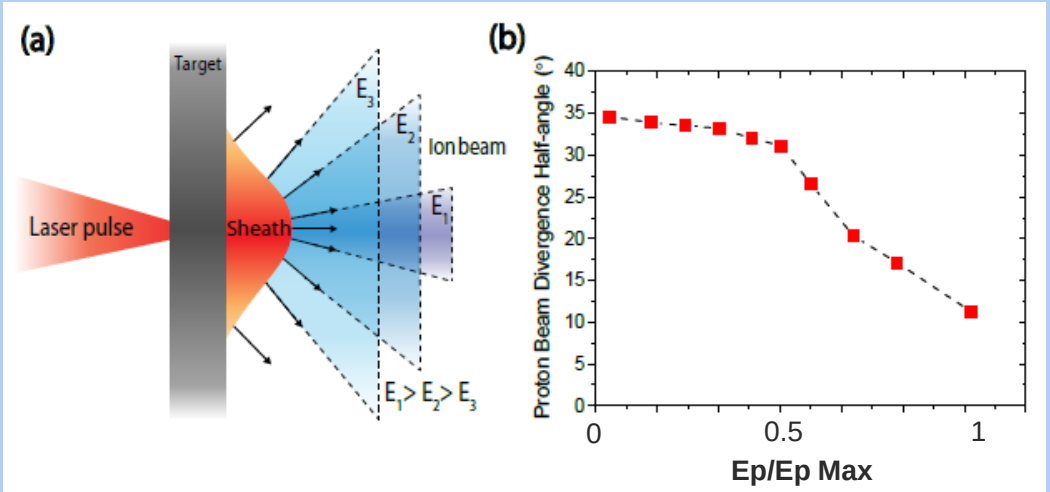
Proton beam characteristics

i)



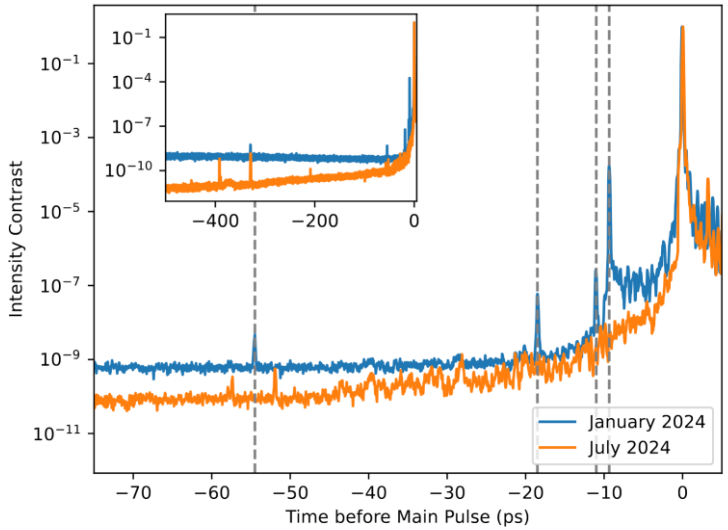
- Broad energy spectrum, up to a maximum cut off energy.

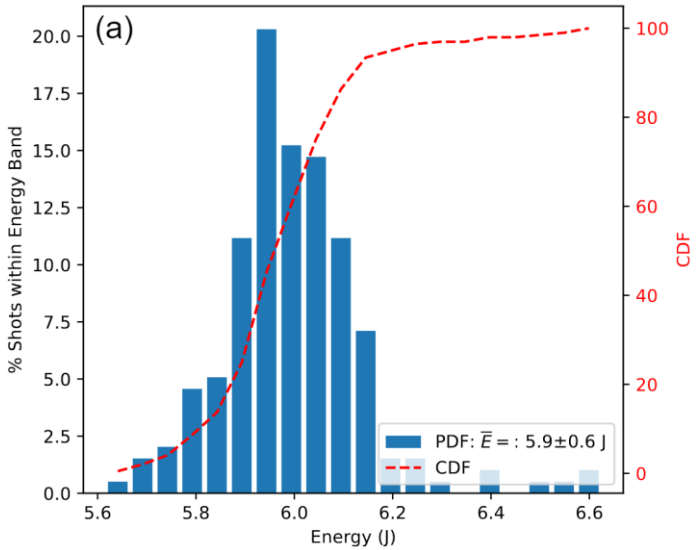
ii)



- Proton energy dependent beam divergence.

Update on Proton Source Parameters/Characterisation





- As reported during the last milestone meeting there were significant prepulses measured in the system which were limiting our proton energy and flux

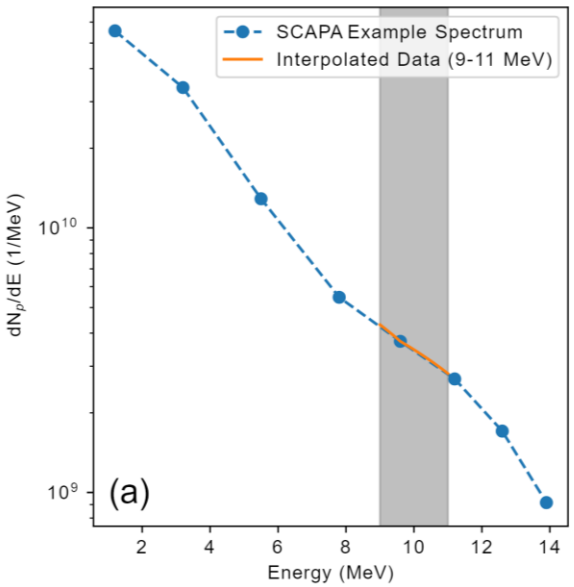
- Offending prepulses have been removed, the contrast is significantly improved and there has been detailed characterisation of laser stability

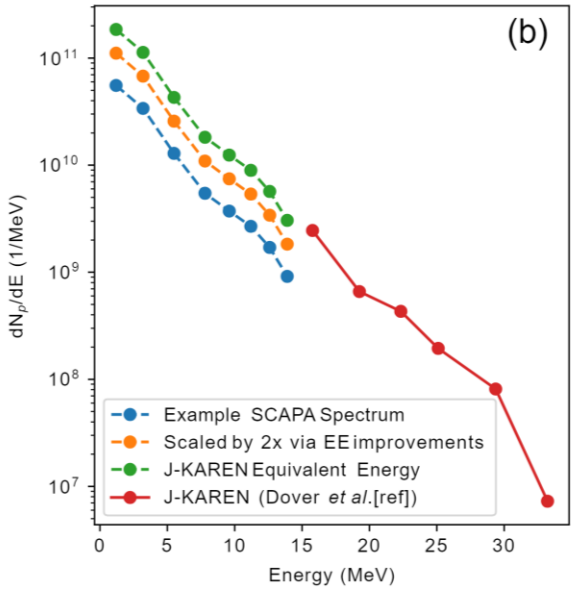
Beamtime Updates

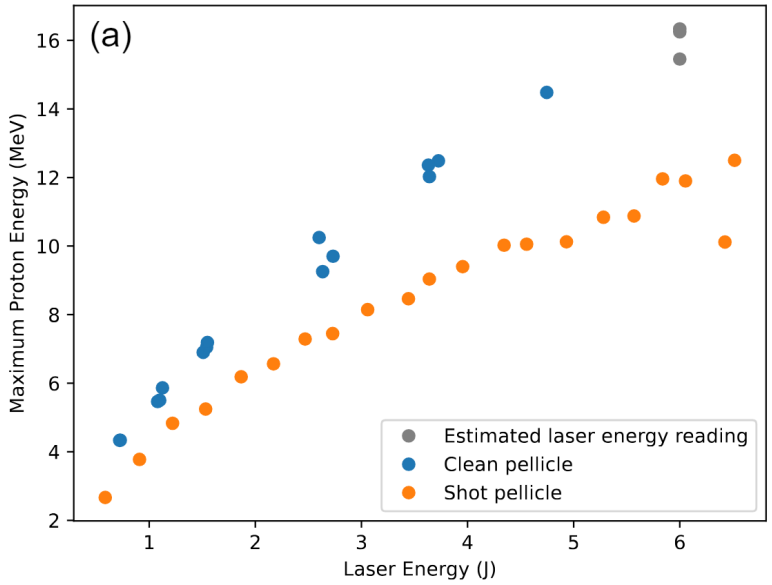
- Performed a 3-week experiment in June/July after laser contrast work in SCAPA and another run in September

- We have now measured protons > 15 MeV on SCAPA at up to 1 Hz repetition rate (typically 0.3 Hz)

- This has been cross calibrated with RCF dosimetry and we find with >10^9 protons at 10 MeV.







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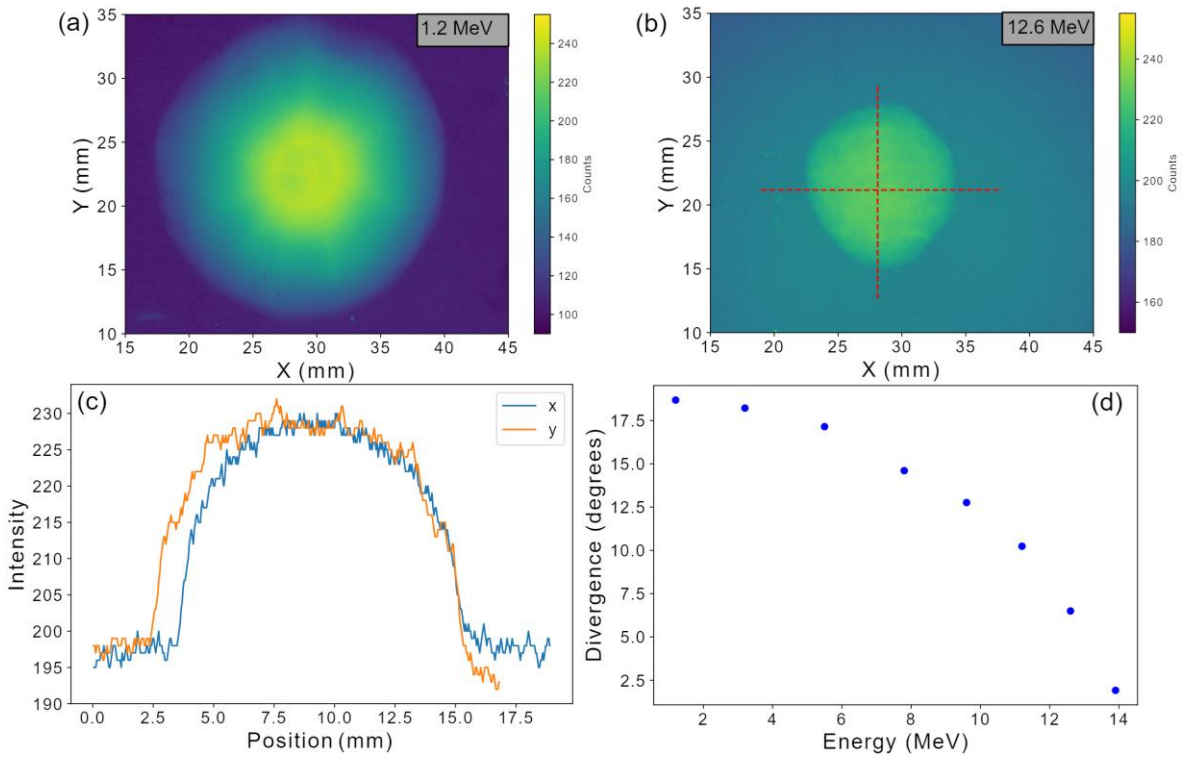
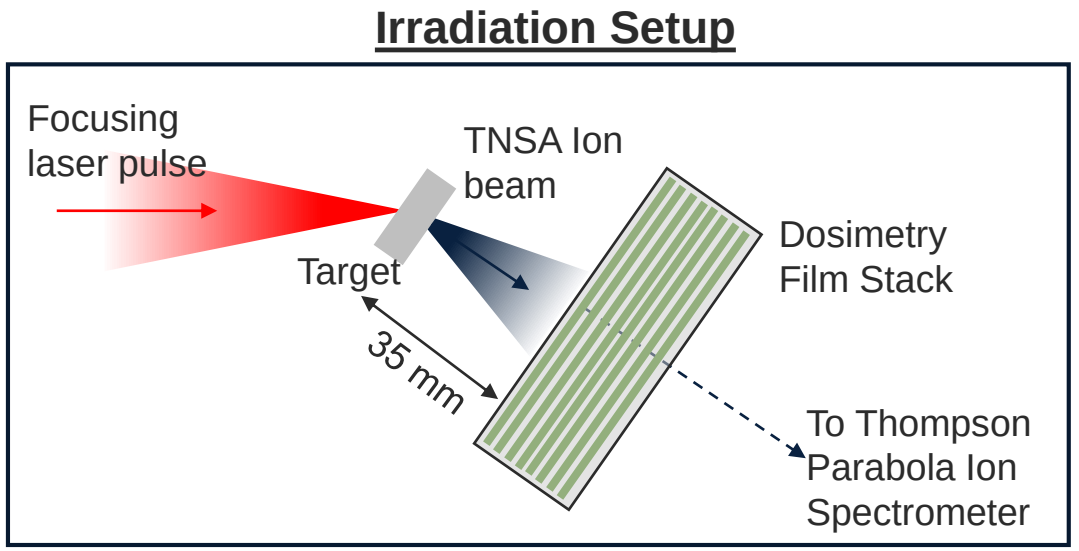
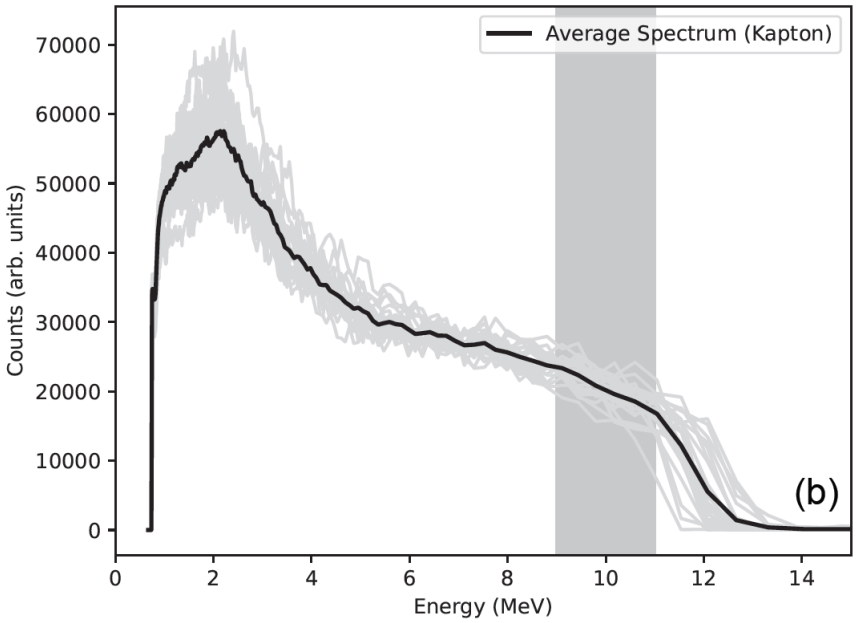


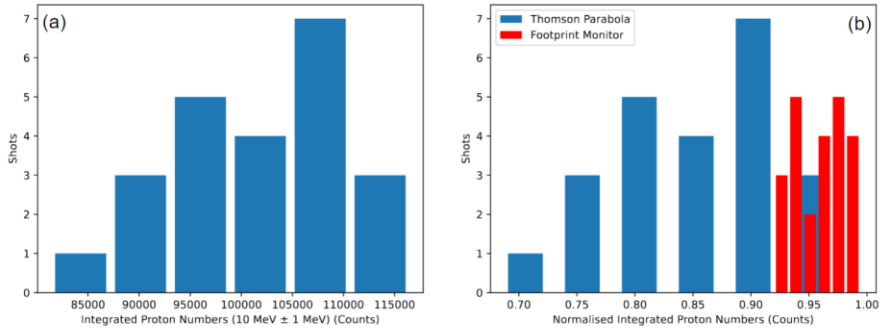


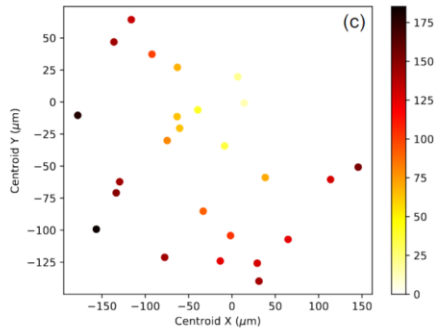
- More detailed measurements made of beam divergence and uniformity

- Uniformity is good at the relevant energies and divergence is as expected

Update on Proton Source Parameters/Characterisation

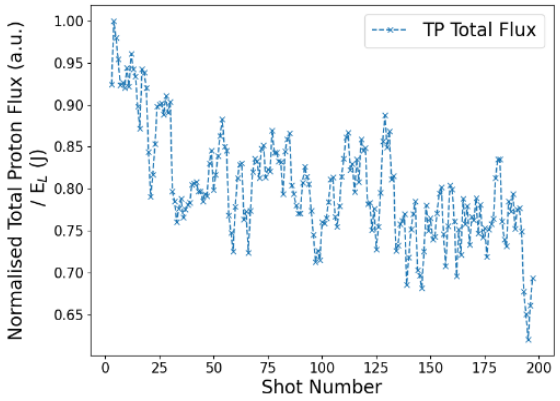


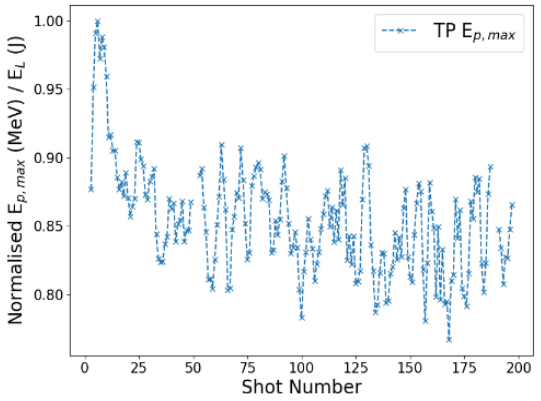


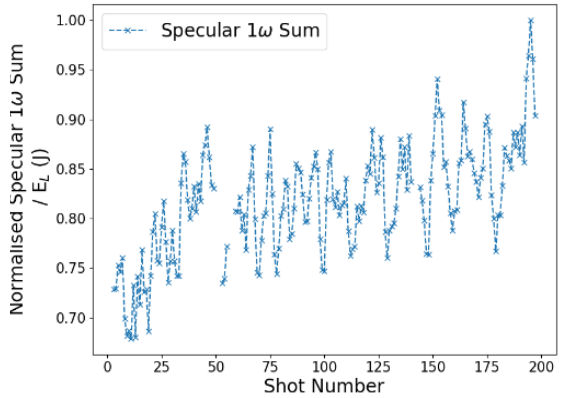


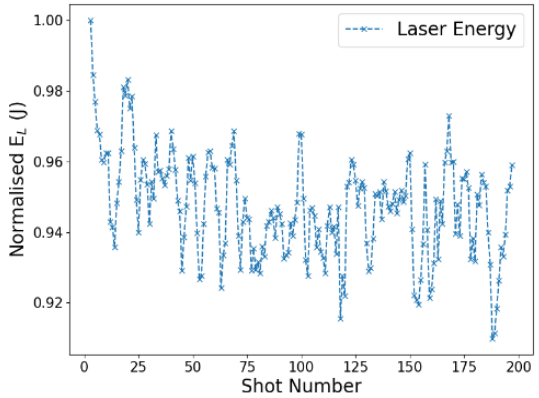
- Part of the experiment focused on measuring shot-to-shot stability of the proton spectrum
- On the TP this is around 8-10% but in reality it is around 2% as TP biases for beam structure and jitter
- We will be able to measure the spectrum on shot and so variation will be accounted for

September beam performance



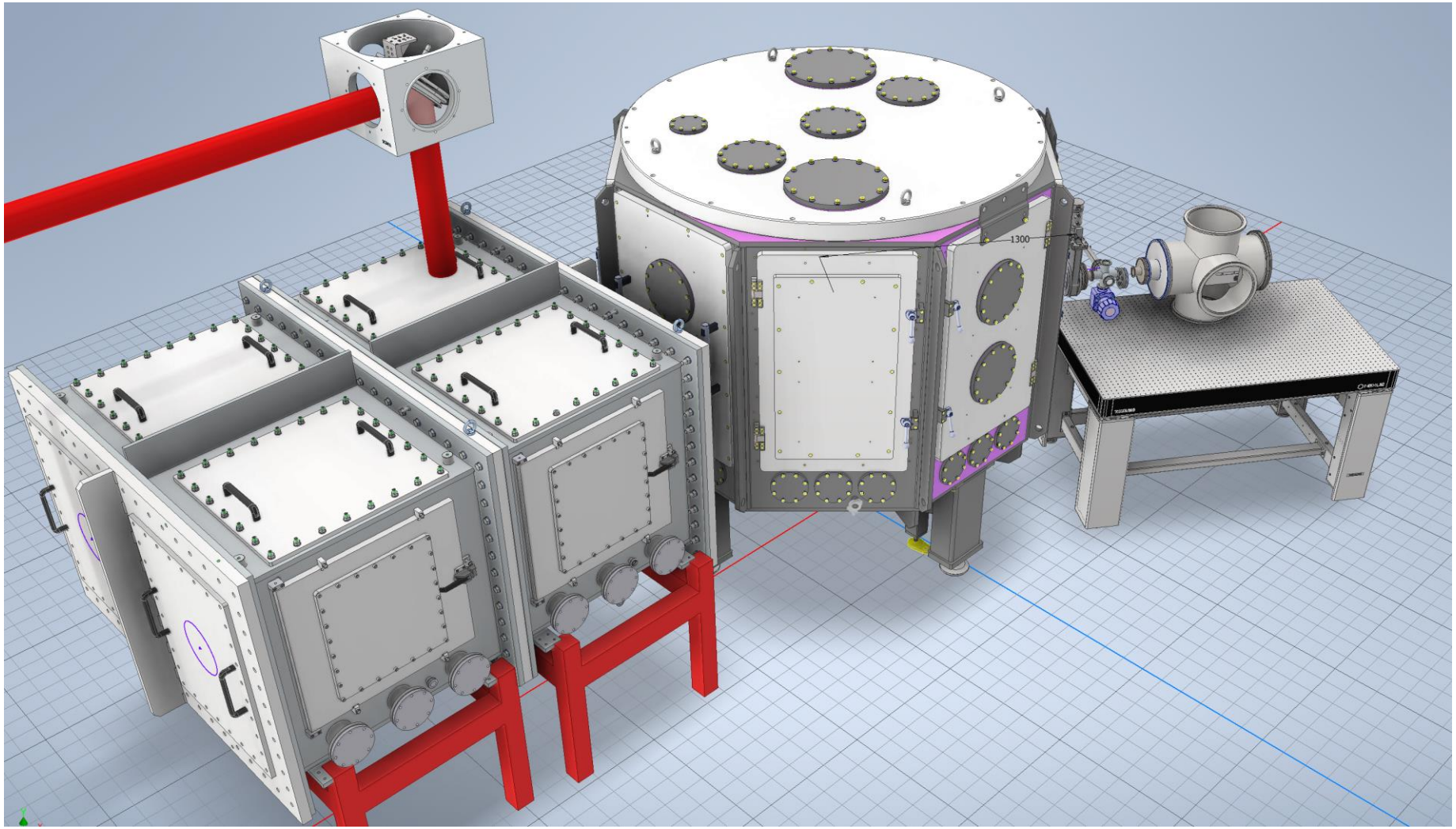






- We performed an experiment in September 2024 which was not related to LhARA….but provided relevant measurements
- During the experiment the same shot was taken >100s of times to investigate the stability of the source
- While the laser parameters are stable the proton flux, max energy are seen to decrease while the specular (the fraction of reflected light increases).
- This was confirmed to be the burning of the pellicle at a rate faster than previously seen….this is concerning and needs to be resolved for continuous operations

Update on beamline design



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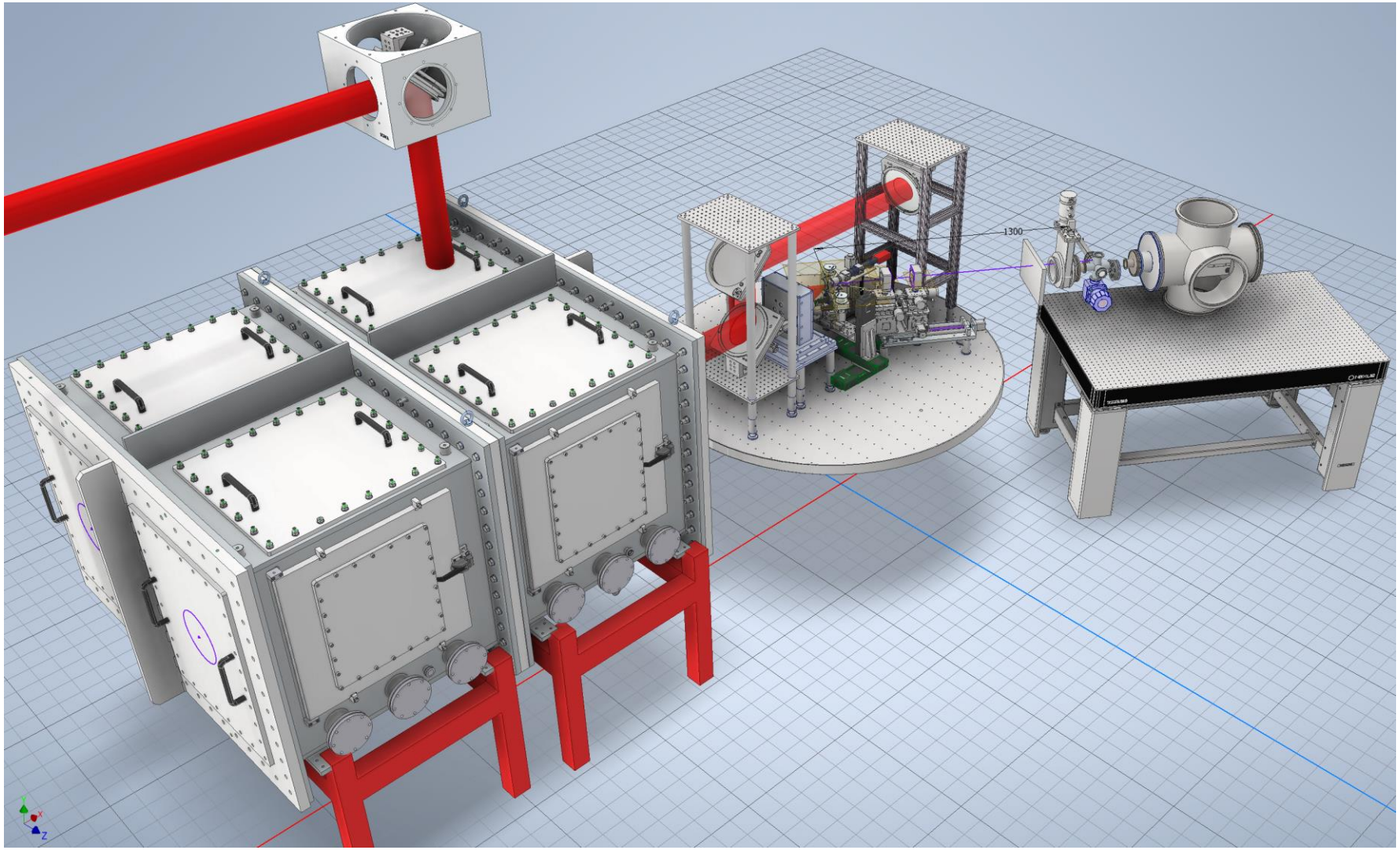

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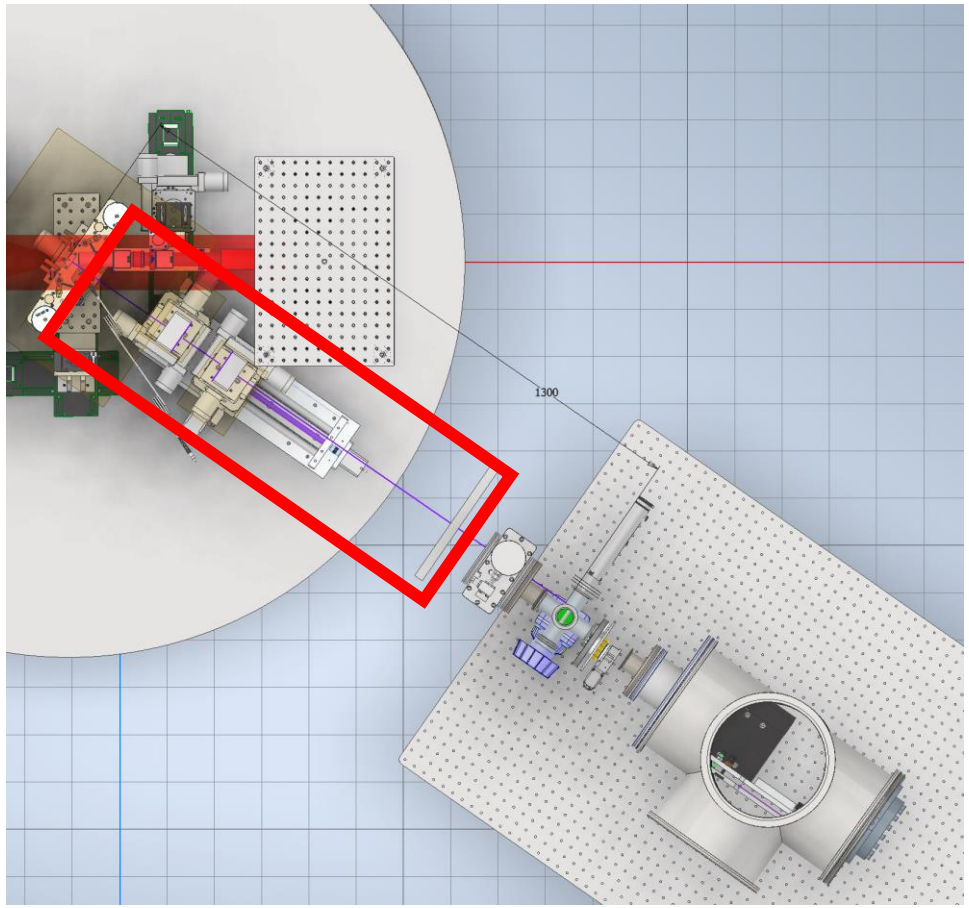
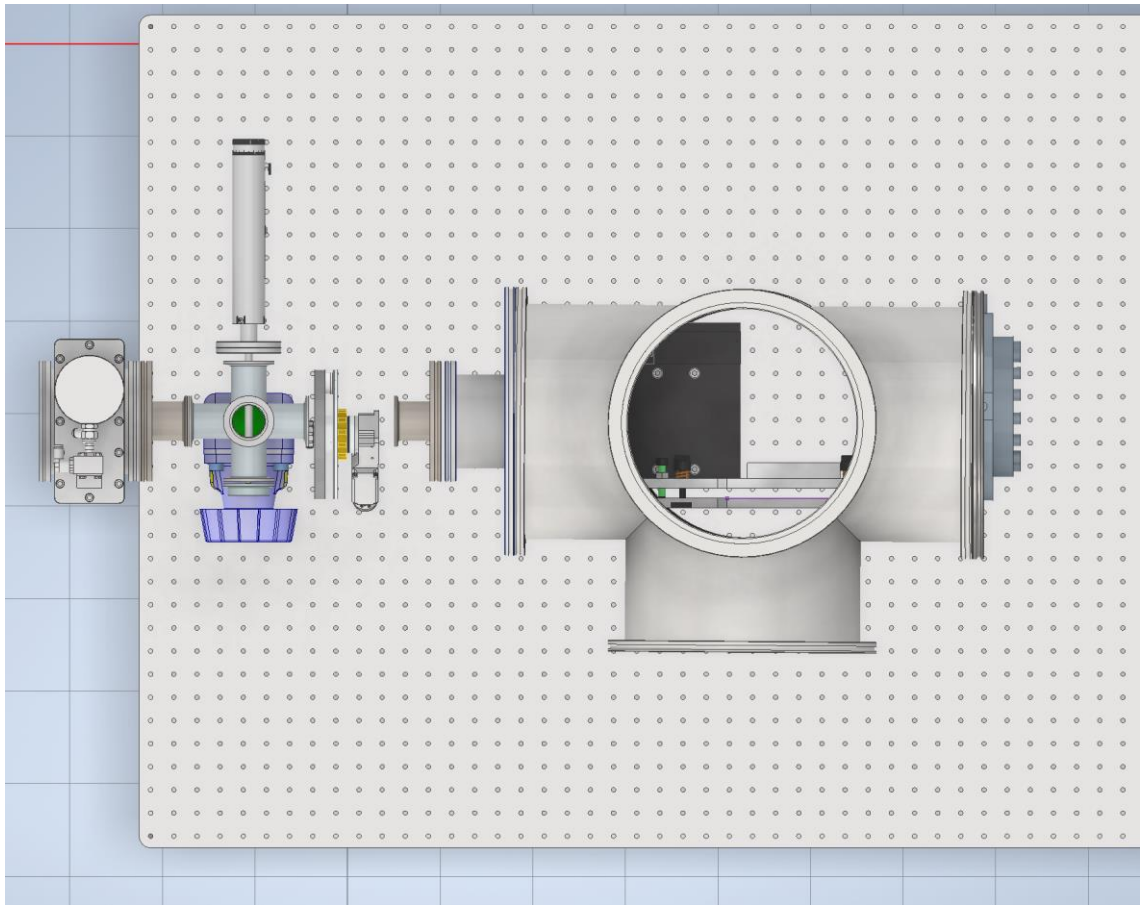
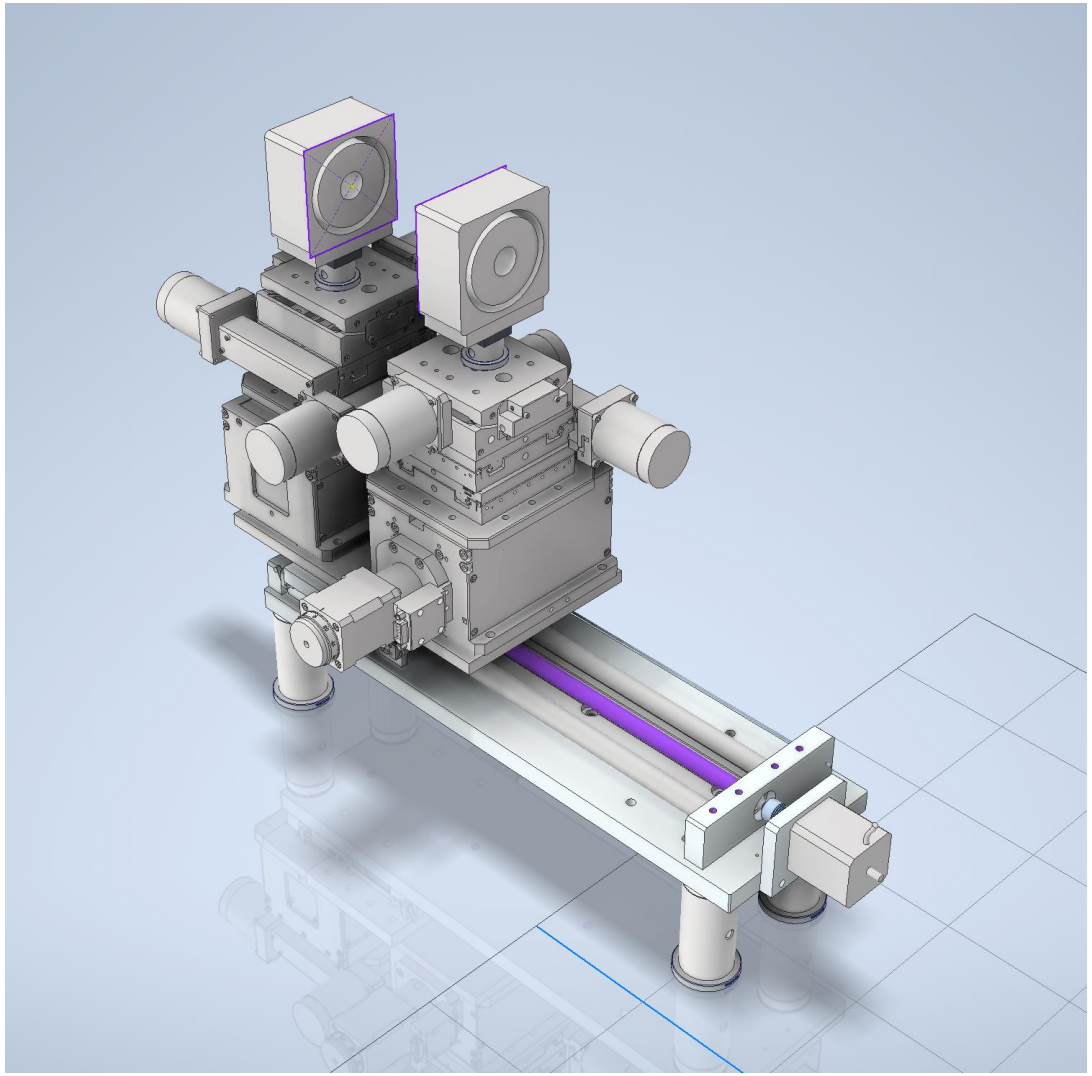




- Progress has been made towards designing the PMQ beamline and cell station setup in SCAPA
- We would be looking to order parts in early January

Update on beamline design



- We are progressing with a simplified PMQ design
- 2 PMQs will be used with one being fixed in place and the other having XYZ and rotation about the central axis as degrees of freedom
- PMQ setup is designed so the magnets are detachable and moveable on a large stage
- This enables normal beam characterisation activity before PMQ use
- The cost of this design is still very high but delivers the flexibility in vacuum we need

Update on beamline model

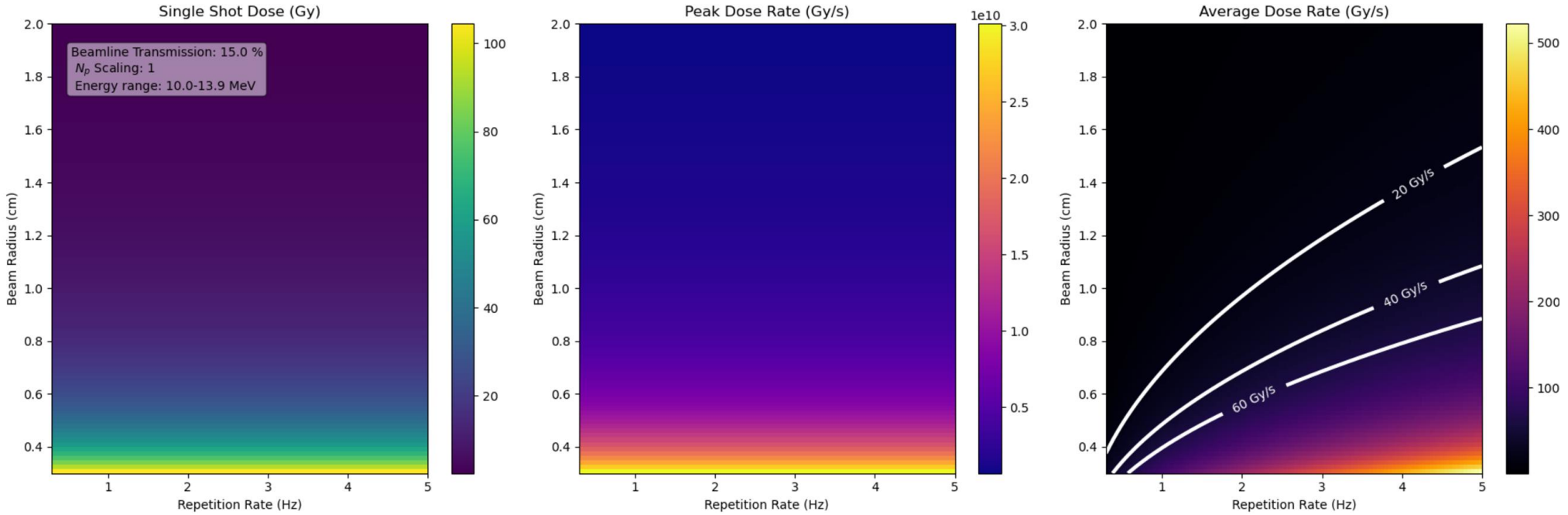
- Developed a simple model to help us identify the optimum set of parameters to go for to reach the biological end goals

- Model uses Pstar CSDA ranges in water to work out the proton dose deposited at the end of the beamline

- Proton numbers derived from experimental data then we are free to vary:
    - Beam radius
    - Beamline transmission
    - Repetition rate
    - Energy-range of protons being considered

- There are a couple of potential solutions for >40 Gy/s (everything is a compromise!)

Update on beamline model



- This simple model suggests operating above 2 Hz with around 600 micron spot we could reach 40 Gy/s
- The model is quite simplistic at the moment. Doesn't take into account losses in the windows or the actual beam profile at the end of beamline
- SCAPA and the systems in Bunker B are not yet operating > 1Hz so this is very much a stretching target. The route to bring this closer is improving the proton flux in SCAPA (December source experiment)

Current system risks/status

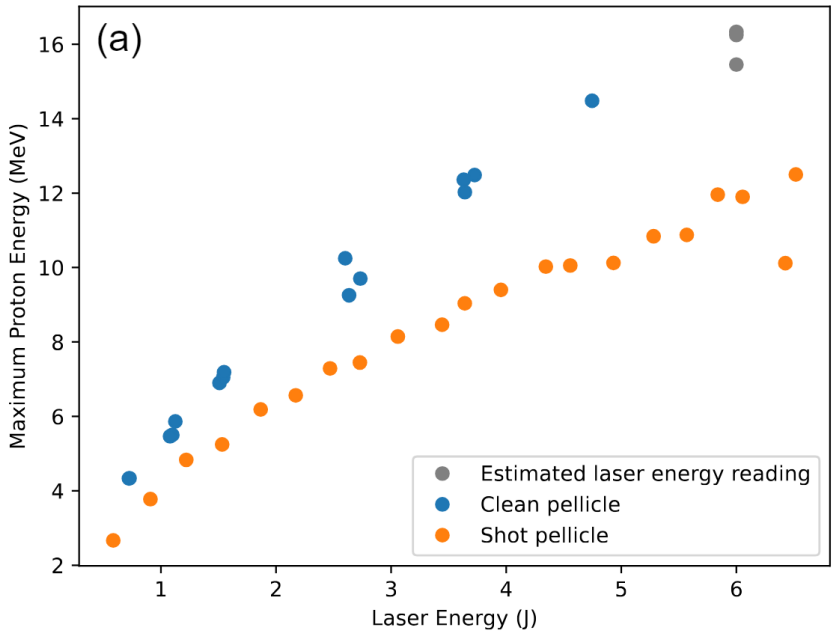
- We have seen some growing damage on the parabola, gratings, final turning mirror and the pellicle

- The gratings are not replaceable in the short term, the final turning mirror is (we might switch to a dielectric mirror to improve longevity)

- We have a new parabola on order with delivery in the next couple months

- The pellicle performance is concerning and more work is needed to resolve

- All of these effects act to reduce energy on target and the quality of the focal spot reducing the performance of the source



Proposed Experiment Stages & Gateways

I. Design & Procurement

- Start of BP1 funding
- Order of PMQ XYZ stage (5-7 week delivery)
- Order of cell station vacuum parts (4 weeks delivery)
- Manufacture of thin window
- Manufacture of Oxford cell station

II. Assembly & Alignment

- Construction of the cell station and updated TP beamline
- Definition of an offline alignment line
- Construction and offline alignment of PMQ setup
- Install of PMQ system in vacuum chamber

III. Source Characterisation

- 1 week of SCAPA beamtime
- Laser Beamline alignment (0.5 days)
- Source optimisation w/o PMQ (0.5 days)
- PMQ transmission, activation and debris test (0.5 days)
- Lanex/beam profiler measurement at end of beamline (1 day)
- PMQ position optimisation (0.5 days)
- RCF measurements through beamline (0.5 days)
- Full cell assembly RCF measurement (0.5 days)

IV. Radiobiology

- 2 weeks of SCAPA beamtime (with a gap between the alignment week)
- Laser Beamline alignment (0.5 days)
- Source optimisation with PMQs (1 day)
- Dosimetry and source stability measurements (2 days)
- Cell irradiation (6.5 days) + regular dosimetry

Summary

- We are in a generally good position for the beam time. The proton source has been developed and optimised during experiments in July 2024 and September 2024…more to come in December 2024
- We have completed model calculations using this data and have identified a way to potentially achieve the required absorbed dose in good time
- The experiment will ramp up from beam and diagnostic optimisation, to dose calibration and then finally the irradiation.
- Potential issues are purchase of the PMQ parts, alignment of the beamline and the long term performance of the system due to pellicle damage

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60

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