

# Automation and Optimization of Laser-Driven Ion Accelerators

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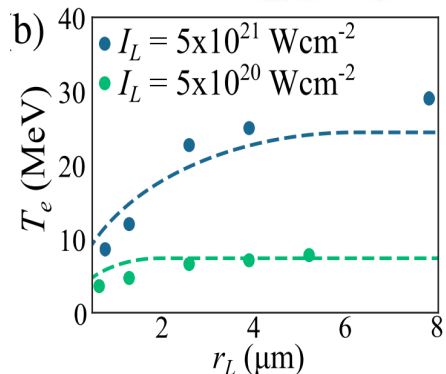
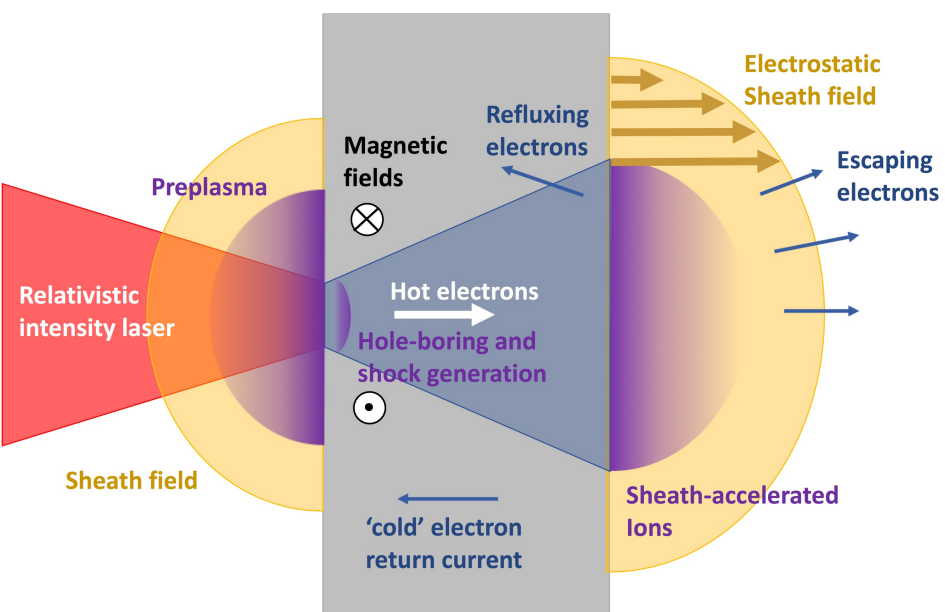
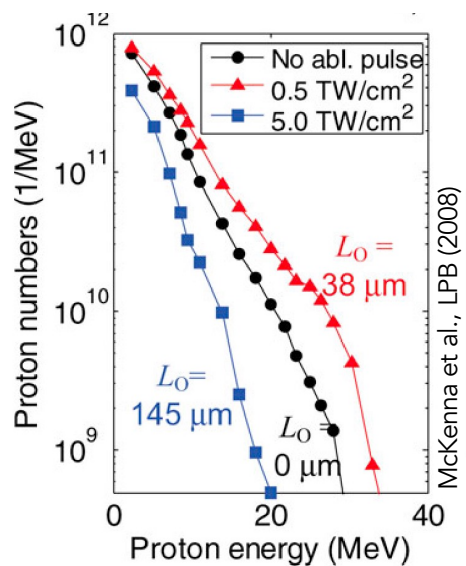
# Automation and Optimization of Laser-Driven Ion Accelerators

- Automation of laser driven proton acceleration
- Real-time Bayesian Optimisation of accelerated proton spectrum
- Stable low-divergence proton beams from Liquid Sheet targets

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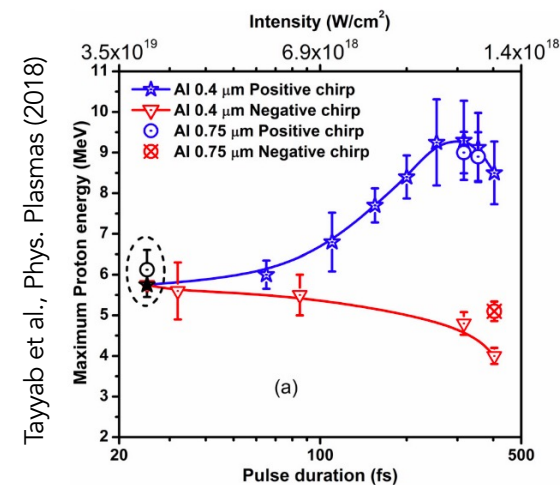
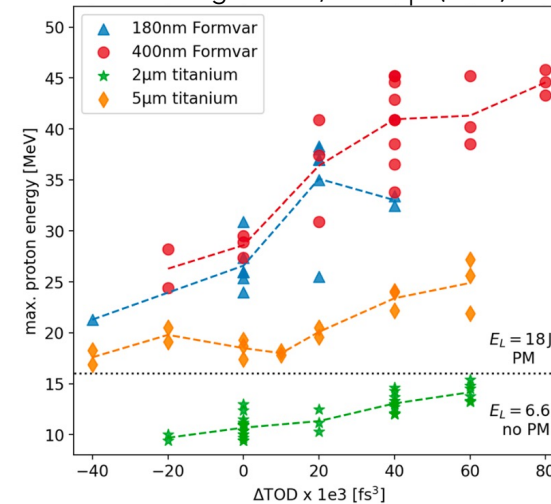
# Target Normal Sheath Acceleration



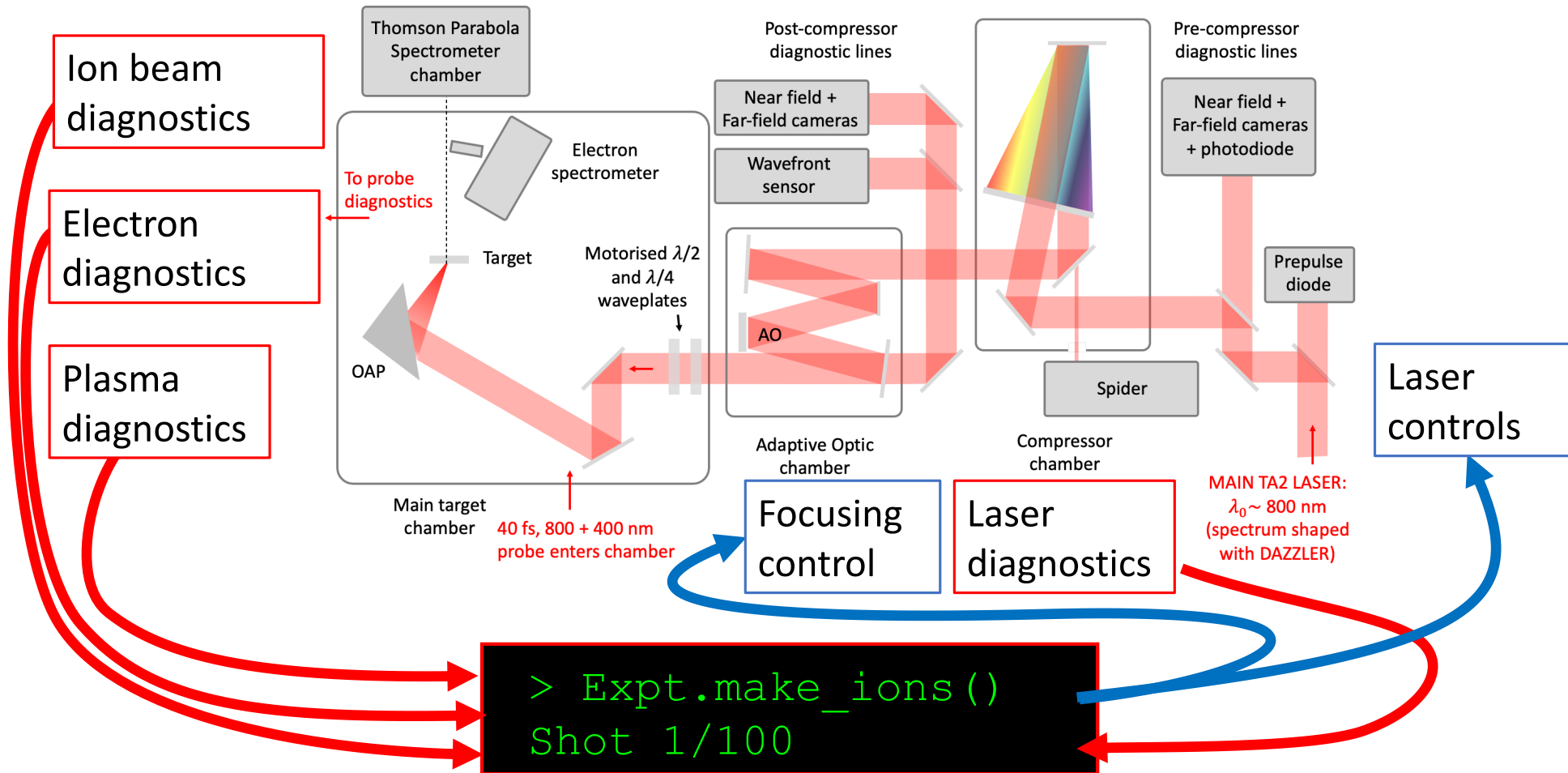
Dover et al., PRL (2020)

- Complex multi-dimensional parameter space
- High repetition rate and reproducible high-performance key for applications

Ziegler et al., Sci. Rep. (2021)



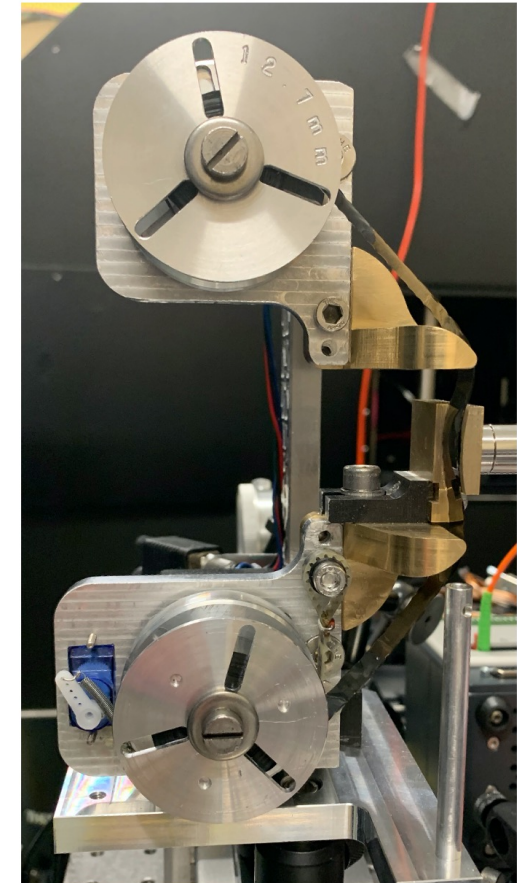
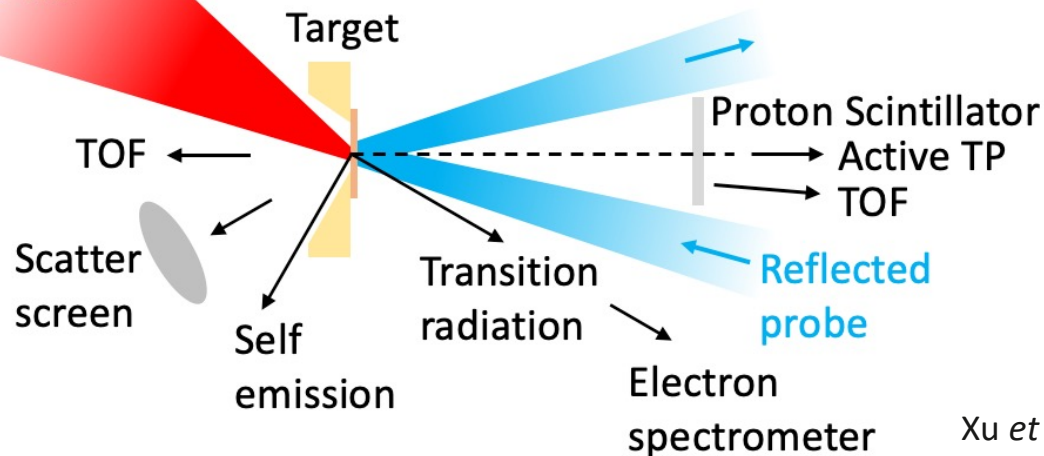
# Automated experimental setup for closed-loop operation



# Automation and optimisation applied protons acceleration

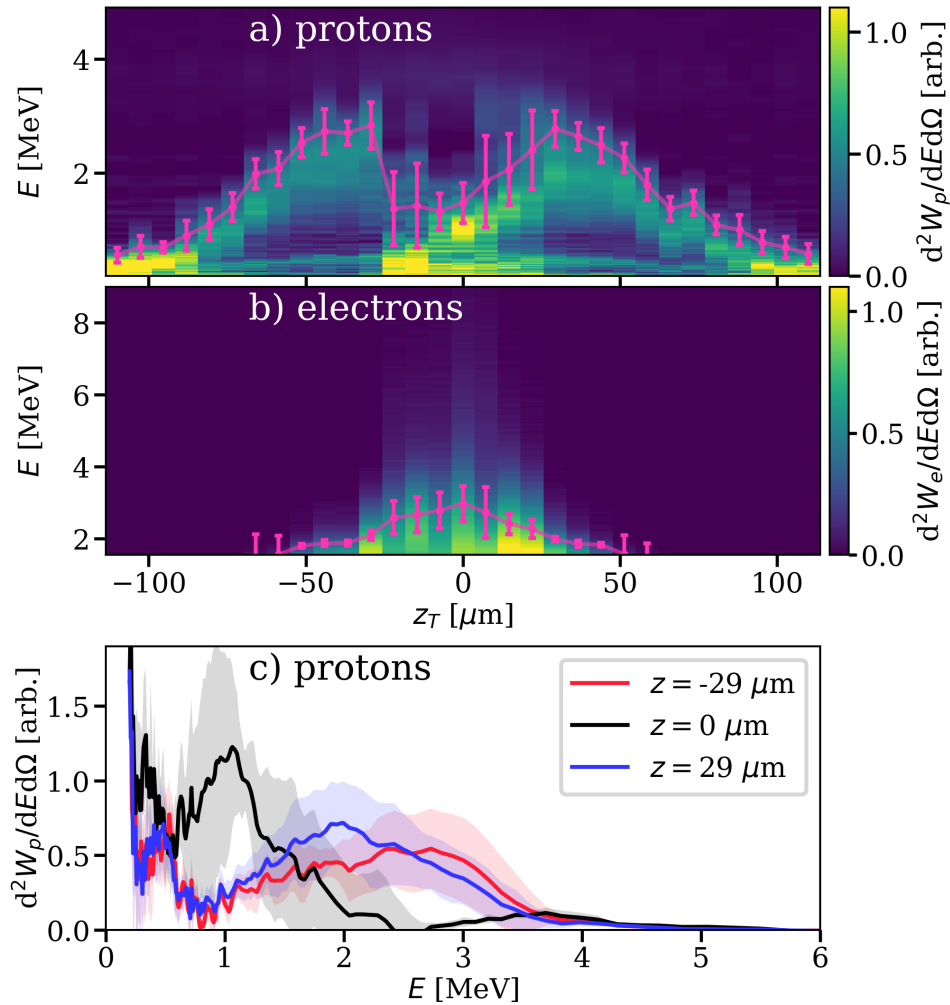
- Experimental on sheath acceleration of proton beams (PI C.A.J. Palmer QUB)
- Applied similar control system and optimisation algorithm as in LWFA experiment (R. J. Shalloo, et al. Nature Comms. 11, 6355 (2020)).
- Used tape target to shoot at 1-5Hz (Developed by N. Xu Imperial College London)

Laser @ 5 Hz  
250-500 mJ  
40 fs

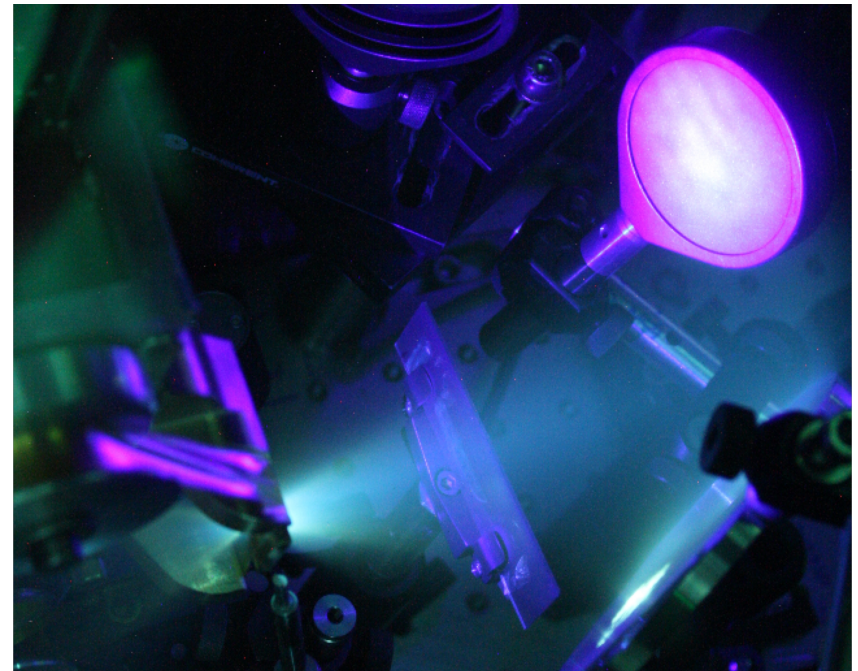


Xu *et al.*, "Versatile tape-drive target for high-repetition-rate laser-driven proton acceleration." HPLSE. 2023;11:e23. doi:10.1017/hpl.2023.27

# Automated z-scan reveals pre-pulses inhibit ion acceleration at tight focus

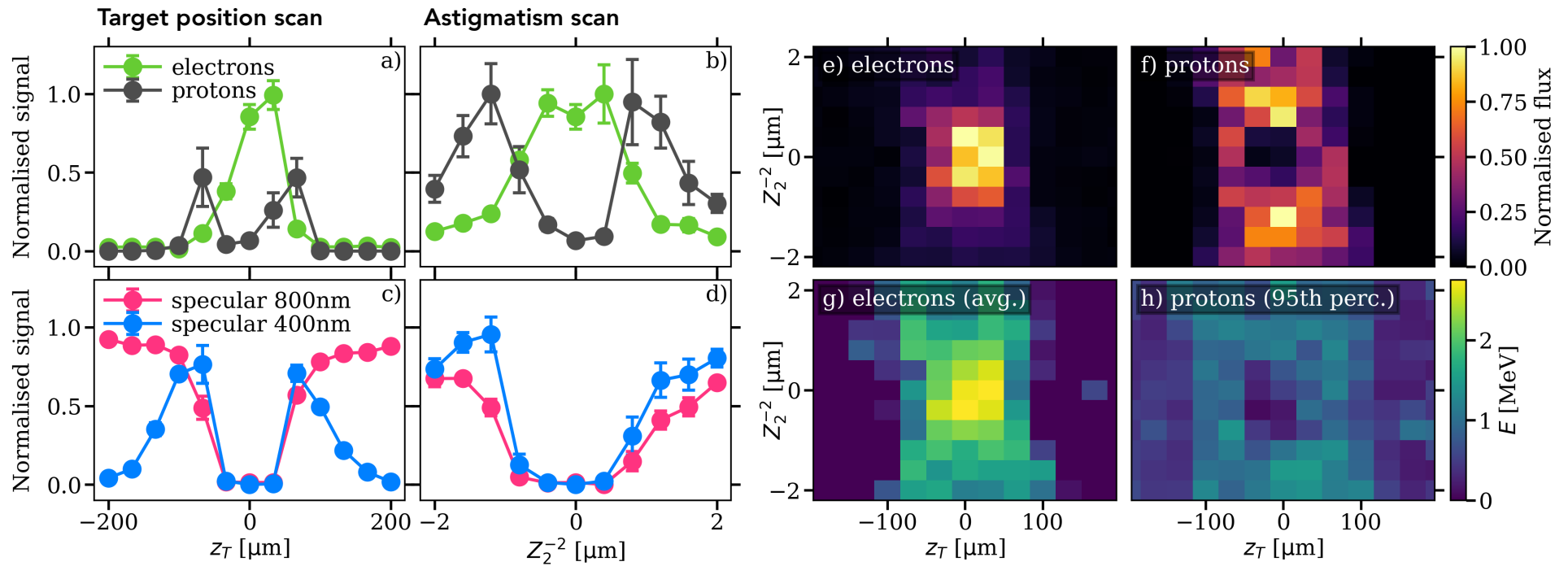


Input laser energy 450 mJ



Loughran *et al.* "Automated control and optimisation of laser driven ion acceleration" HPLSE, 1-11. 2023  
doi:10.1017/hpl.2023.23

# Multi-dimensional grid scans



- Optimization of proton beam properties over complex multidimensional parameter space a real challenge

Target: 13  $\mu\text{m}$  Kapton

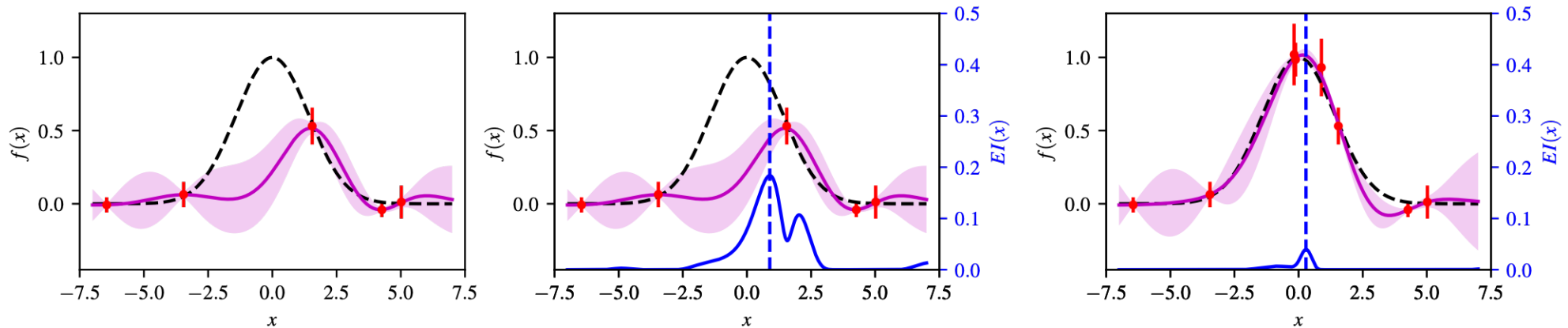
Laser energy:  $453 \pm 40$  mJ



# Automation and Optimization of Laser-Driven Ion Accelerators

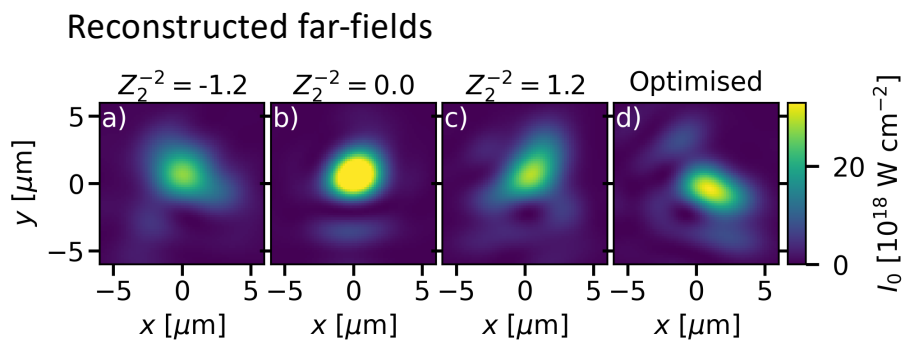
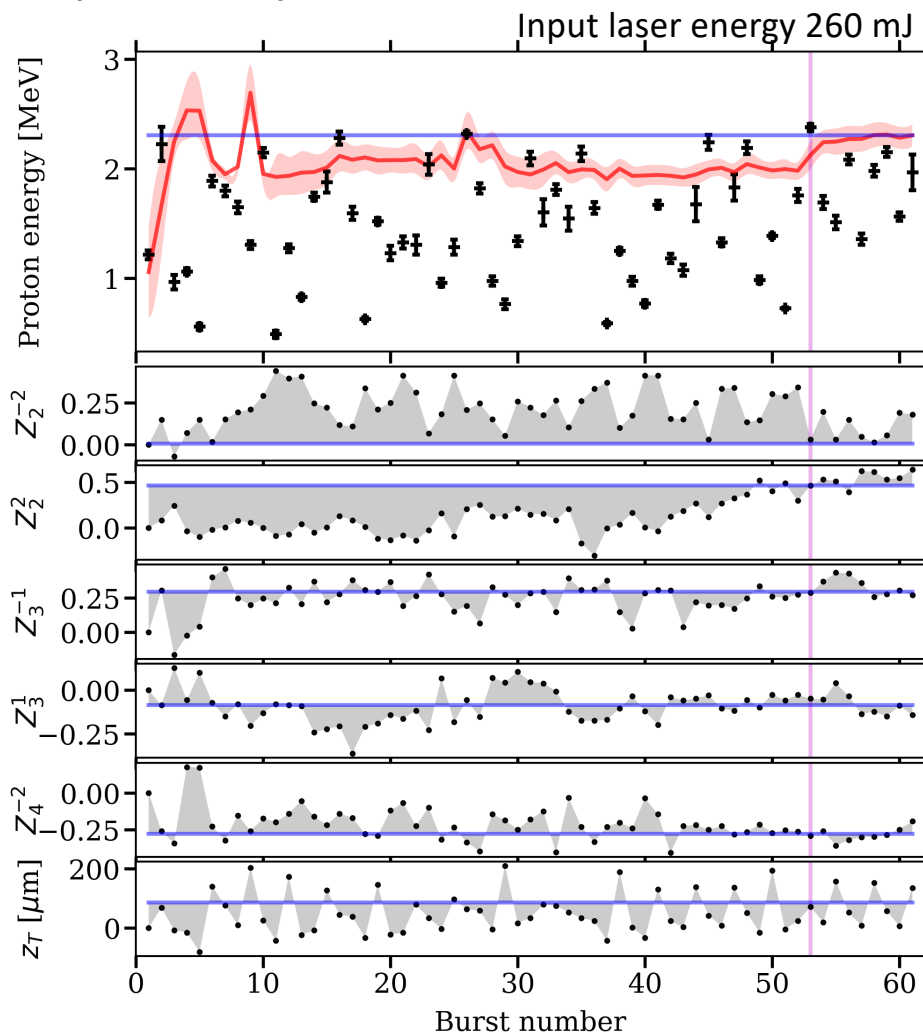
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# Bayesian optimisation using Gaussian process regression



- **Gaussian Process Regression (GPR):** Build a multi-dimensional model from noisy measurements by specifying a 'kernel' which determines correlations between values
- **Acquisition Function:** Uses the model to calculate where in parameter space to sample next.
- **Optimisation:** Through successive sampling increase the accuracy of the model and try to find the optimum.

## Bayesian Optimisation finds better combination of defocus and aberrations



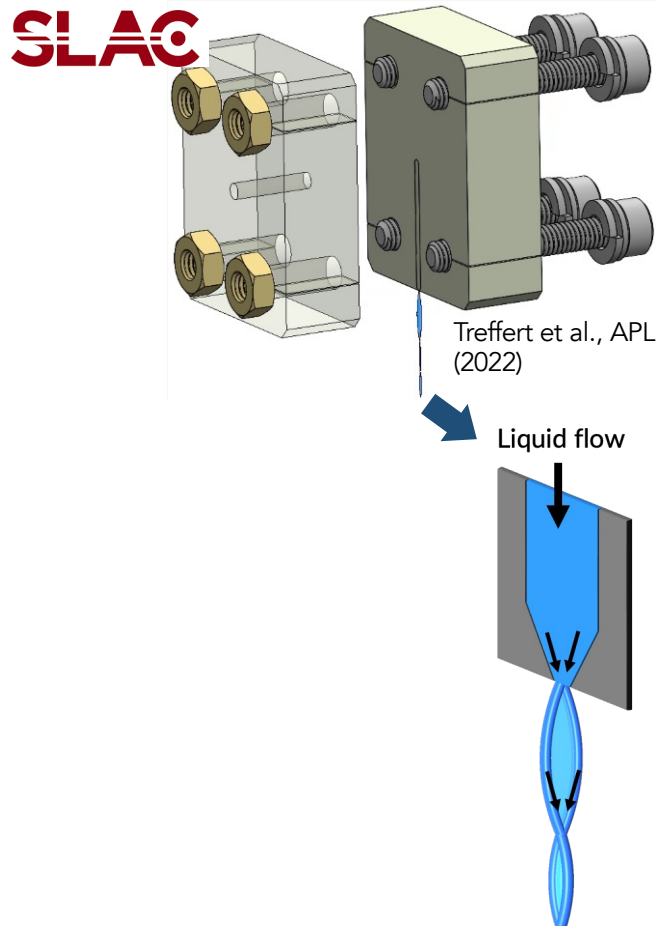
- Modelling required a feedback system to obtain more accurate input parameters
  - Biggest issue was drive positioning
- Final focal spot shows combination of aberrations yields maximum proton beam energy

Loughran *et al.* "Automated control and optimisation of laser driven ion acceleration" HPLSE, 1-11. 2023  
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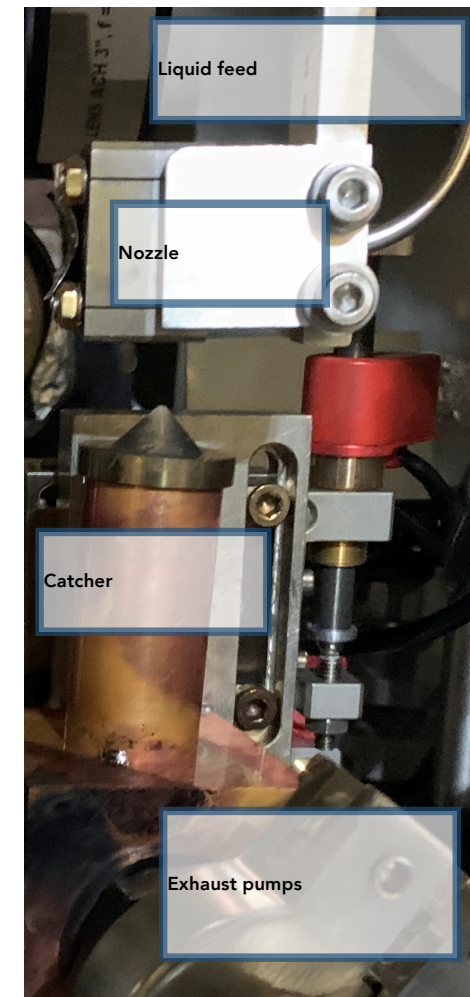
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# Novel water sheet as a potential kHz ion source

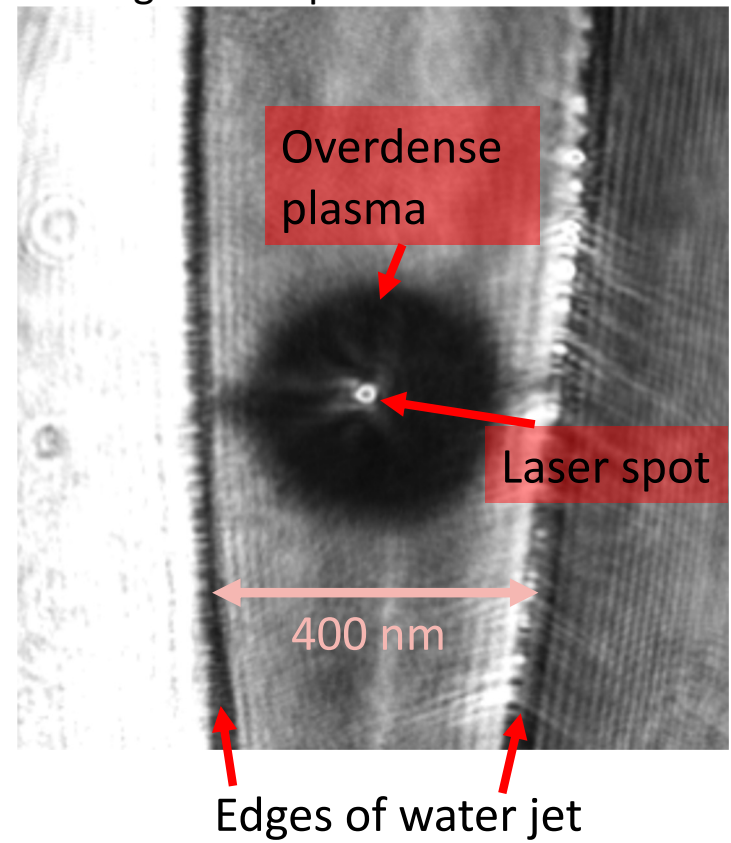


- Liquid sheet nozzle developed by SLAC
- Implemented in Gemini TA2 with 240 mJ laser energy
- Target thickness tunable from 100s nm to few microns

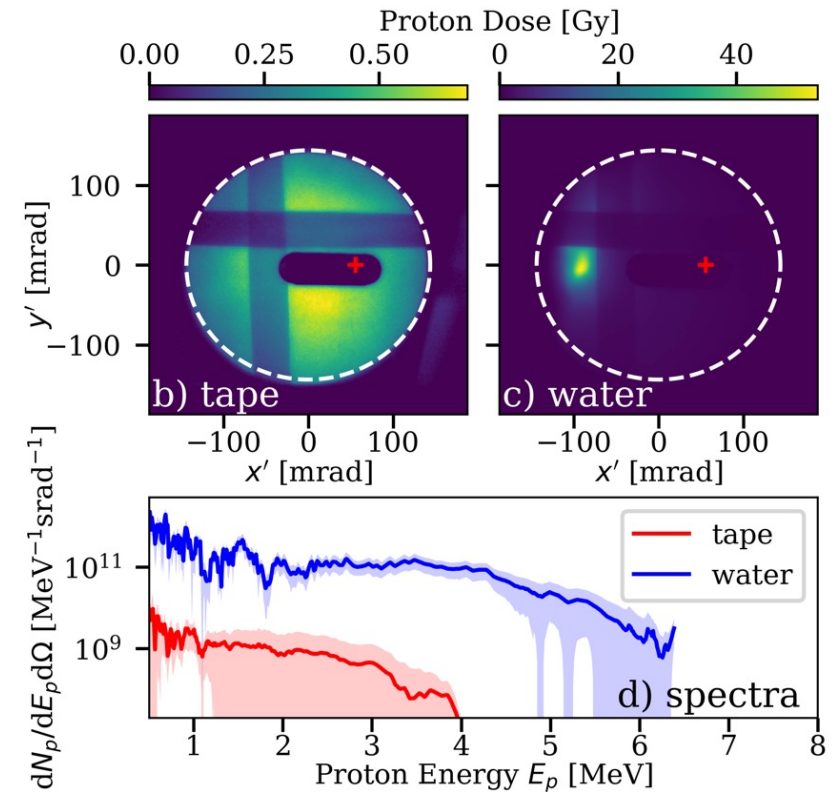
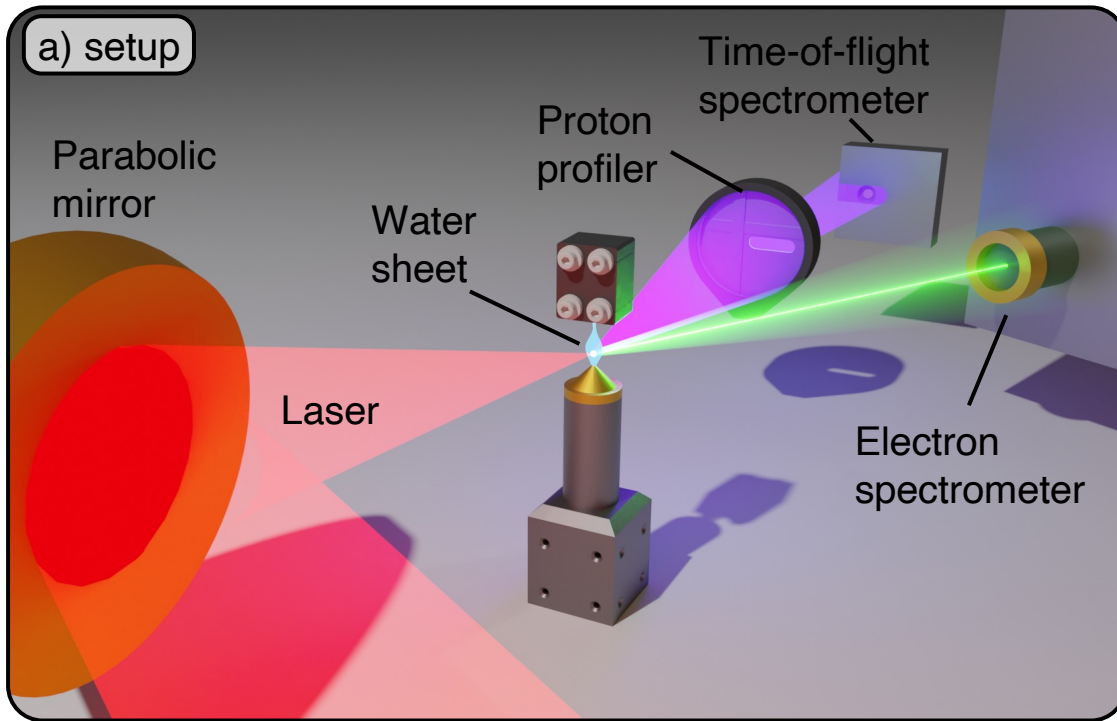


# Novel water sheet as a potential kHz ion source

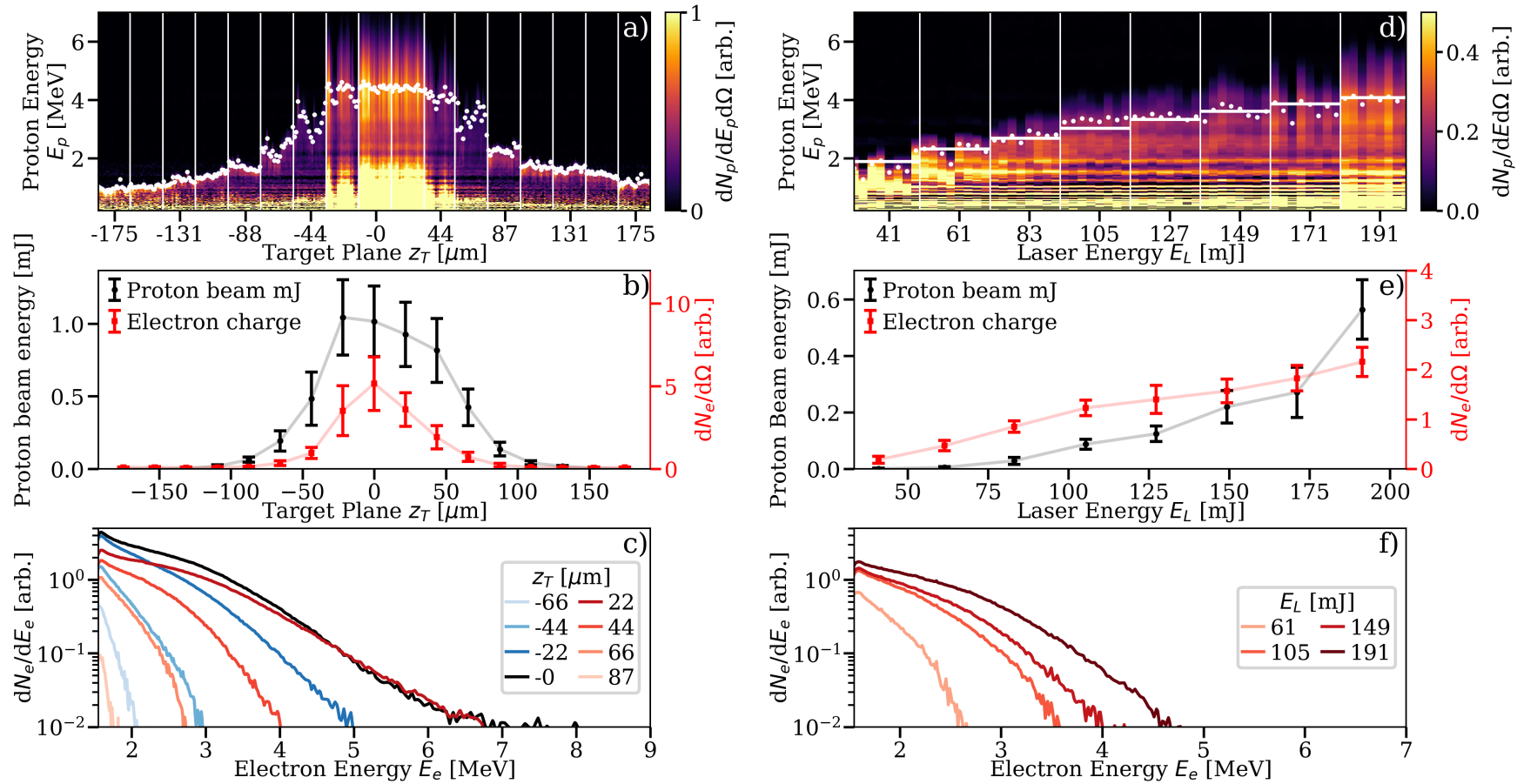
Longitudinal probe at  $t = +670$  fs



# Observed greatly enhanced proton beams compared to tape target

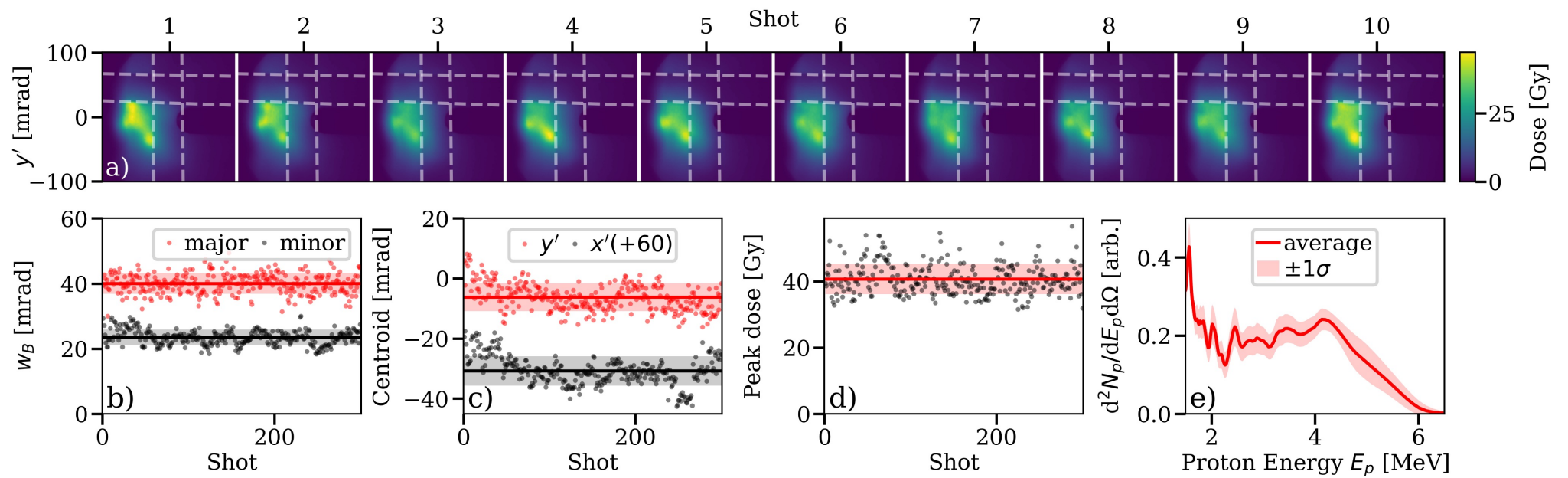


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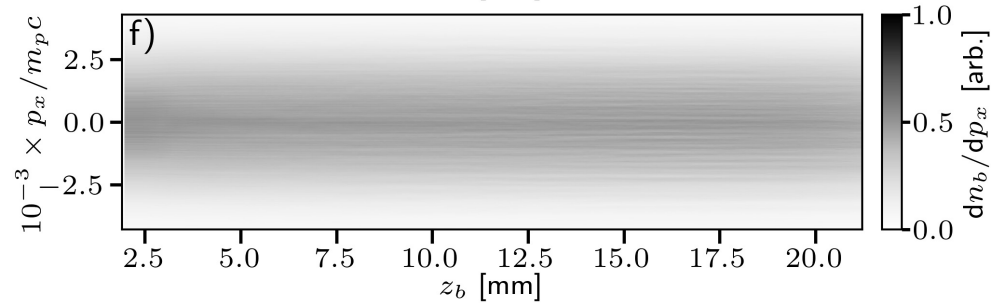
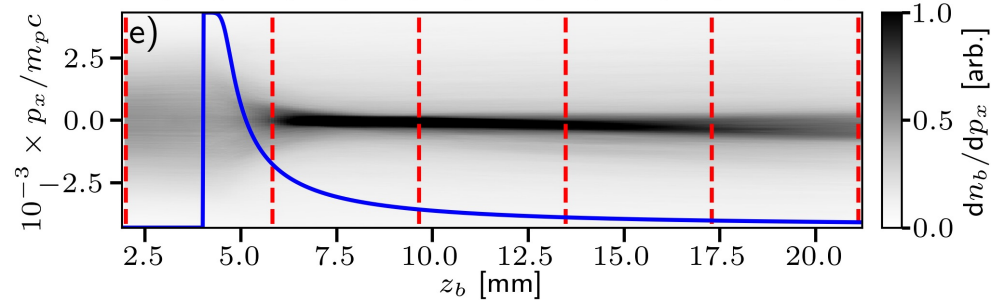
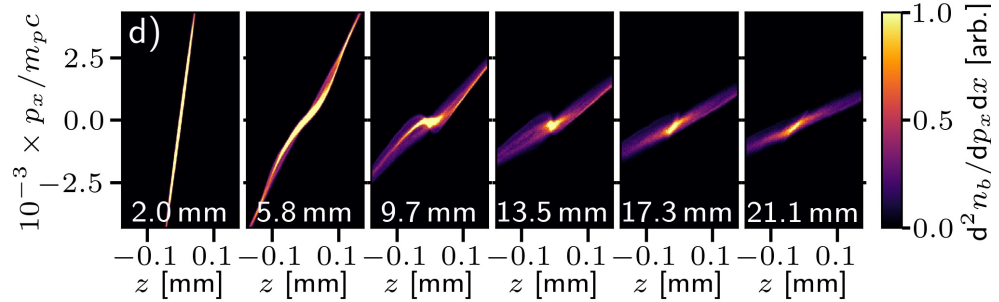
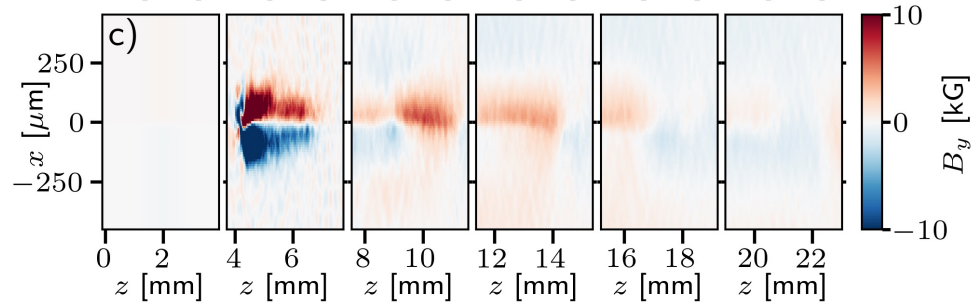
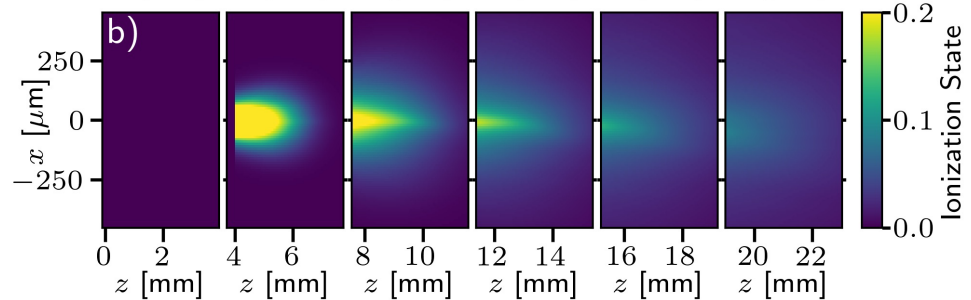
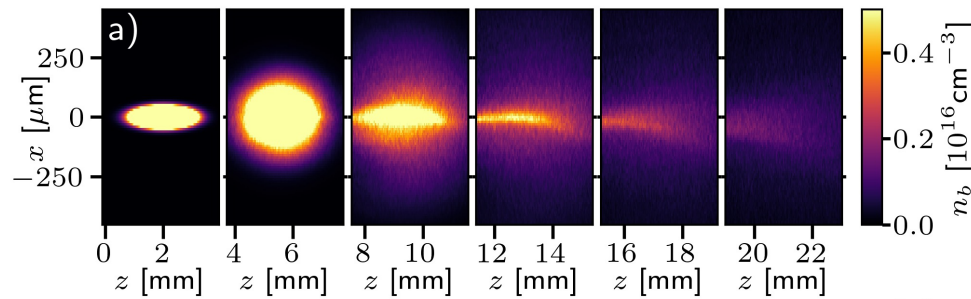




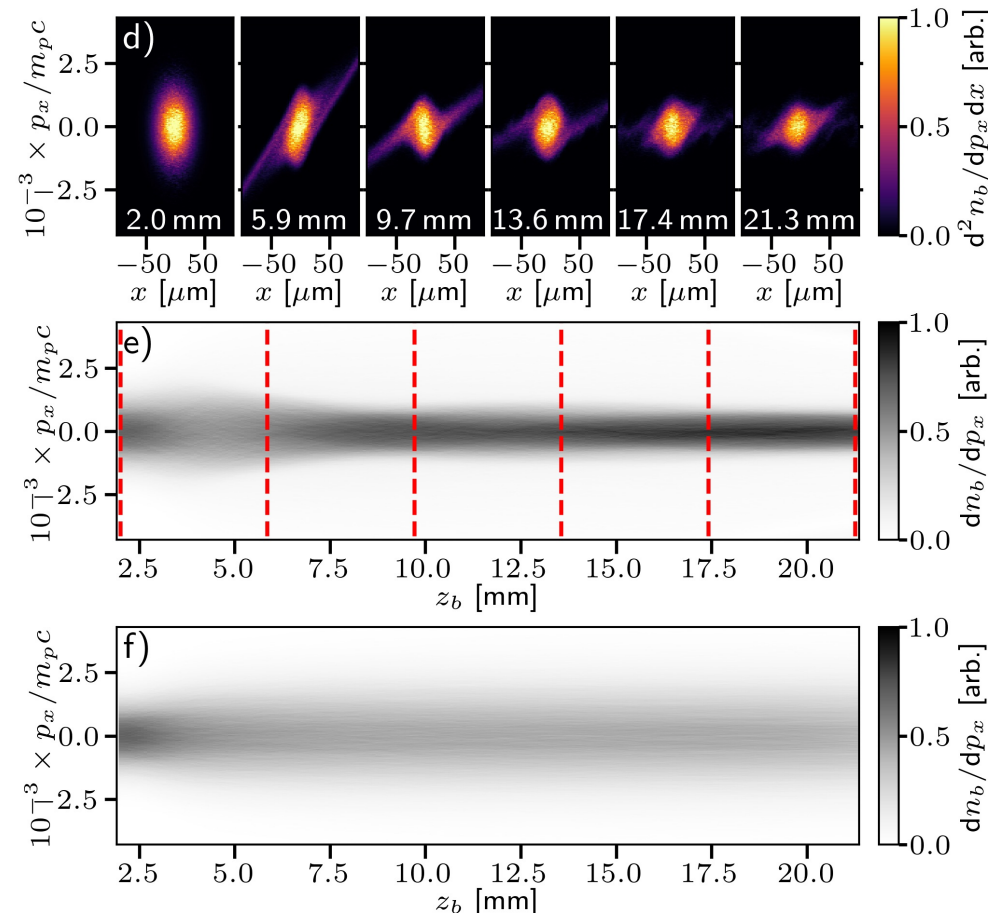
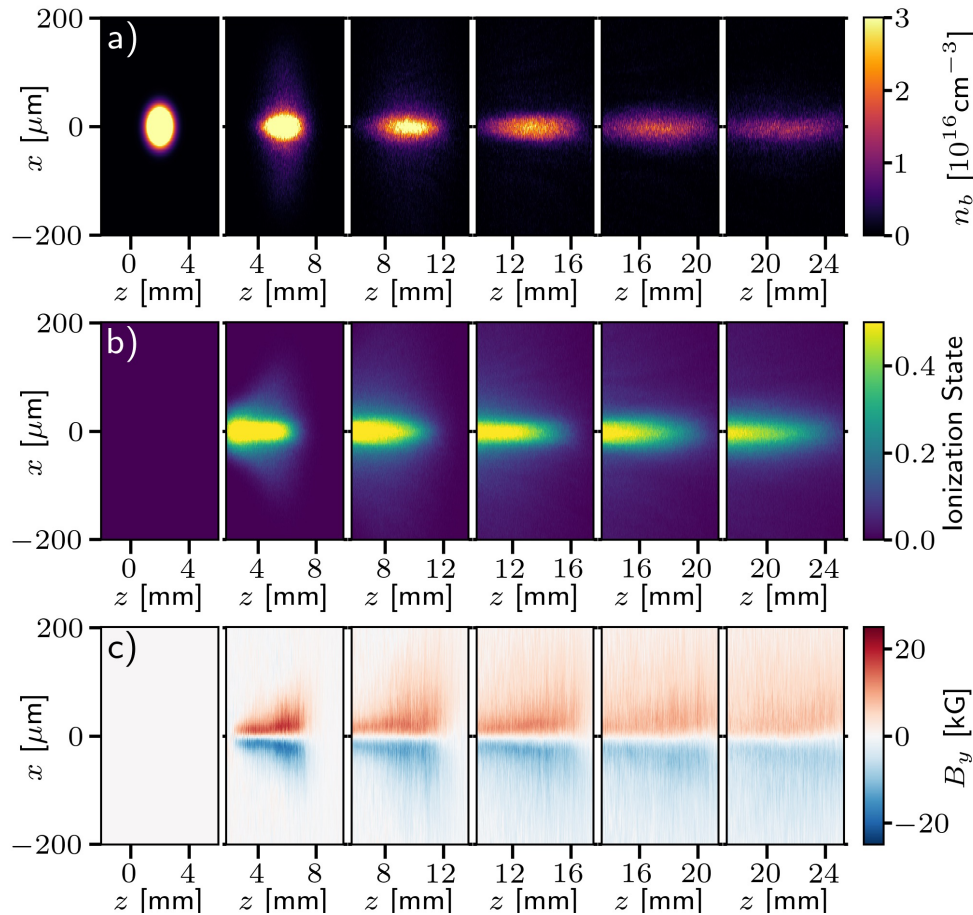
# Remarkable stability in beam profile over 100s of shots



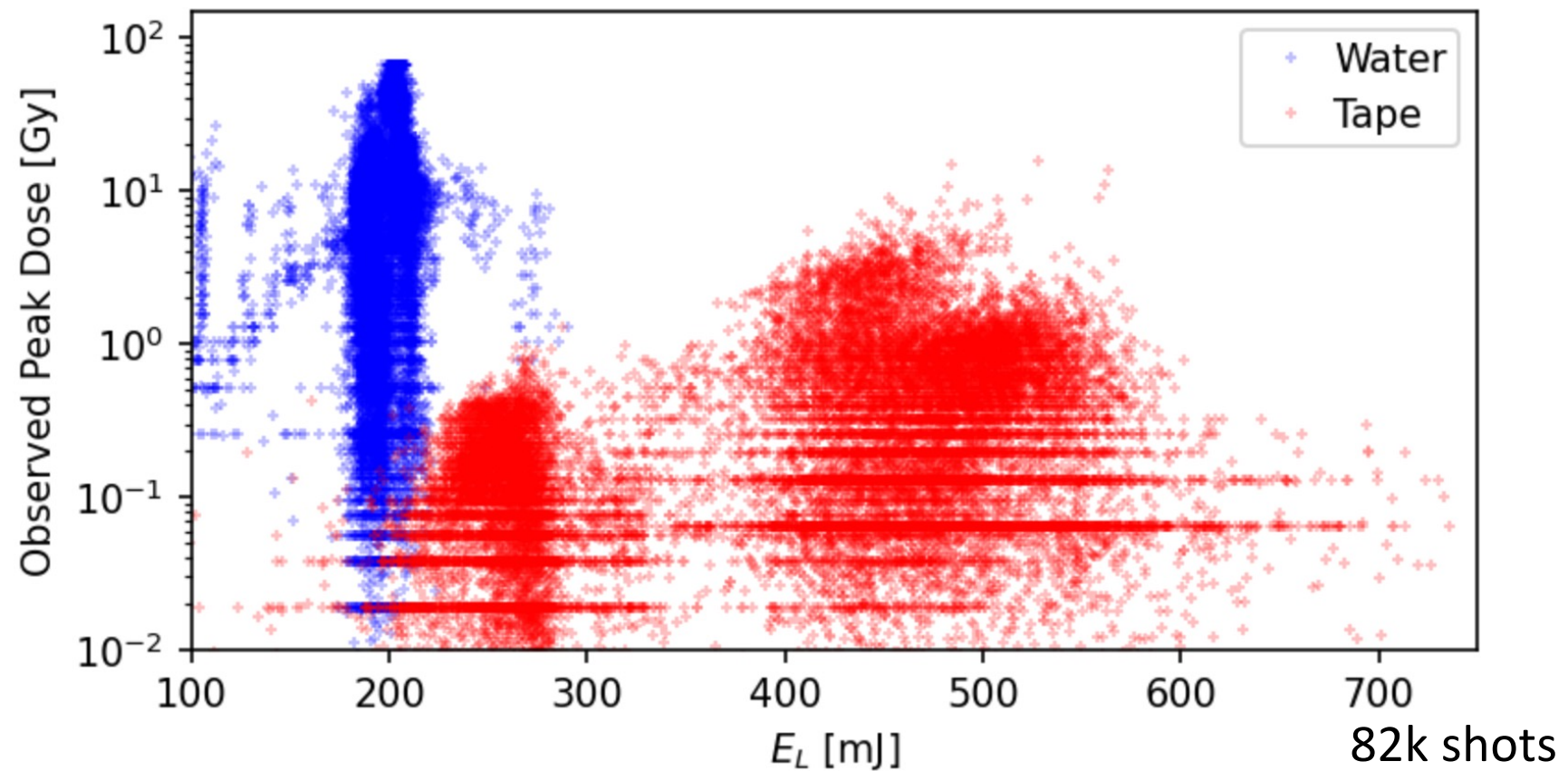
# Simulations using simulated neutral vapour density profile



# Simulations using simulated neutral vapour density profile



# Large database of results generated from experiment



# Thank you again to our collaborators and to you for your attention

**QUB:** B. Loughran, M. Borghesi, C. Hyland, O. McCusker, D. Margarone, P. Parsons, M. J. V. Streeter,

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