AE100 - Ion Acceleration at ATF

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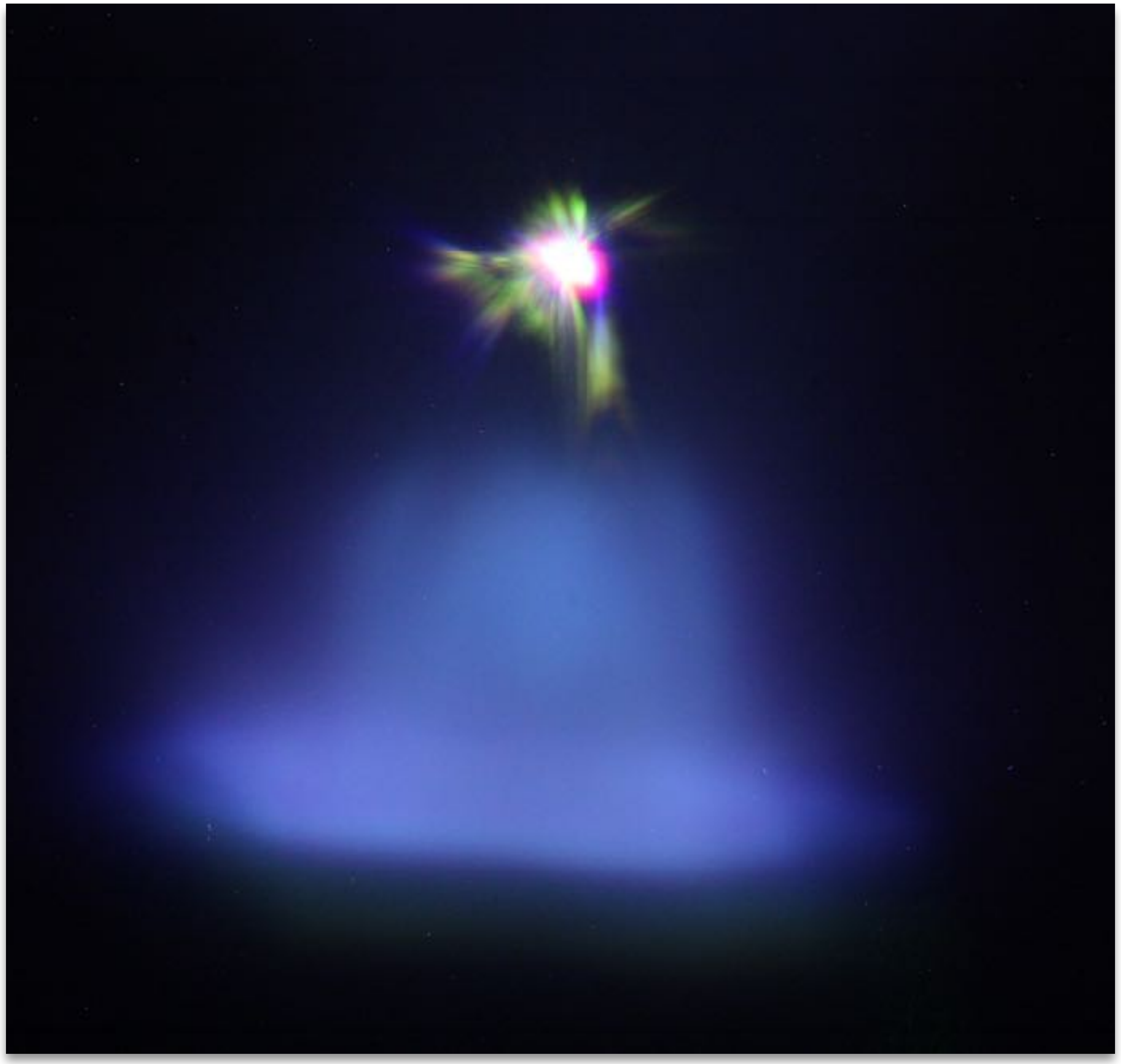


ATF User Meeting,
26th March 2024

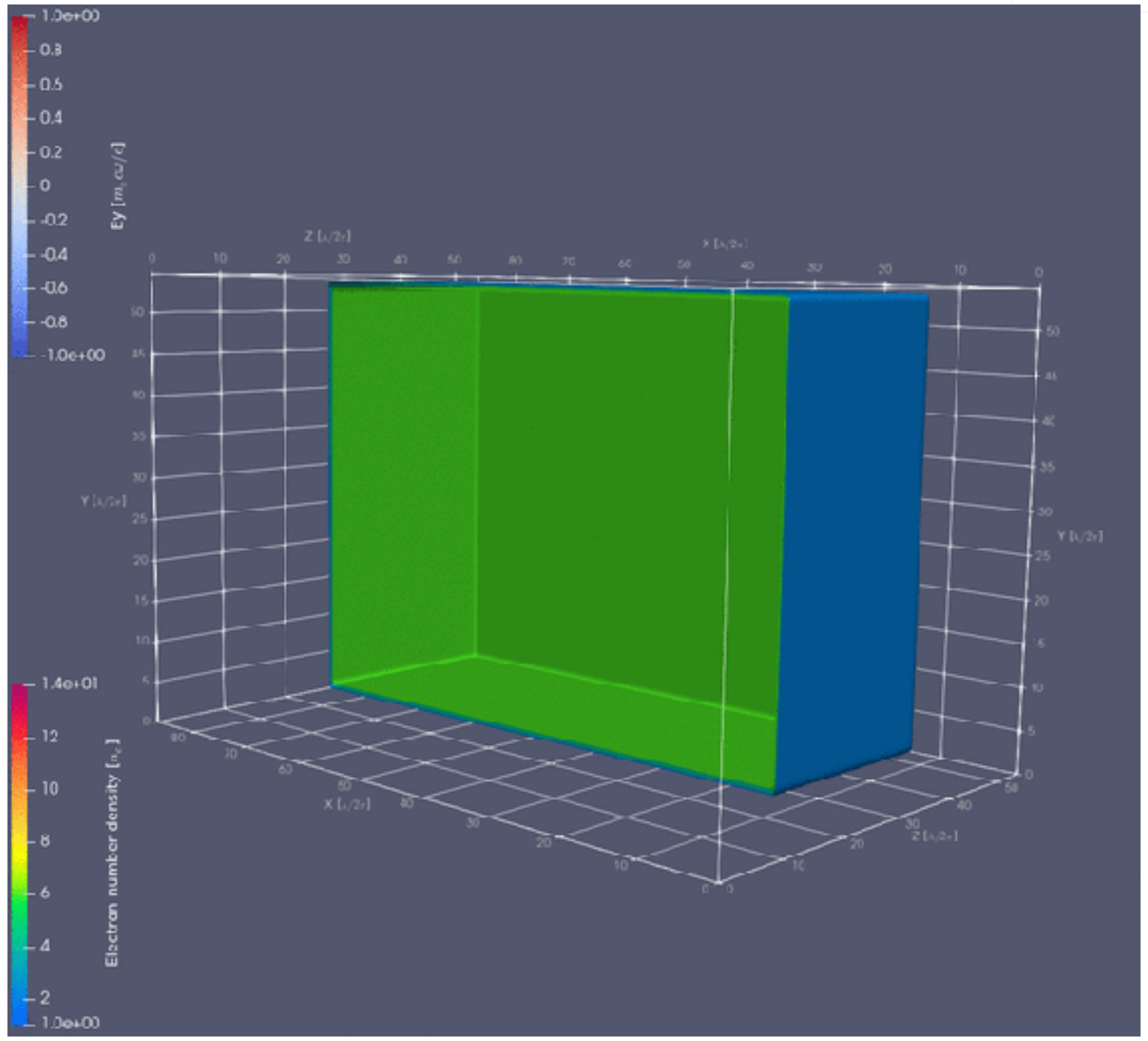
Active Funding: STFC ST/V001639/1

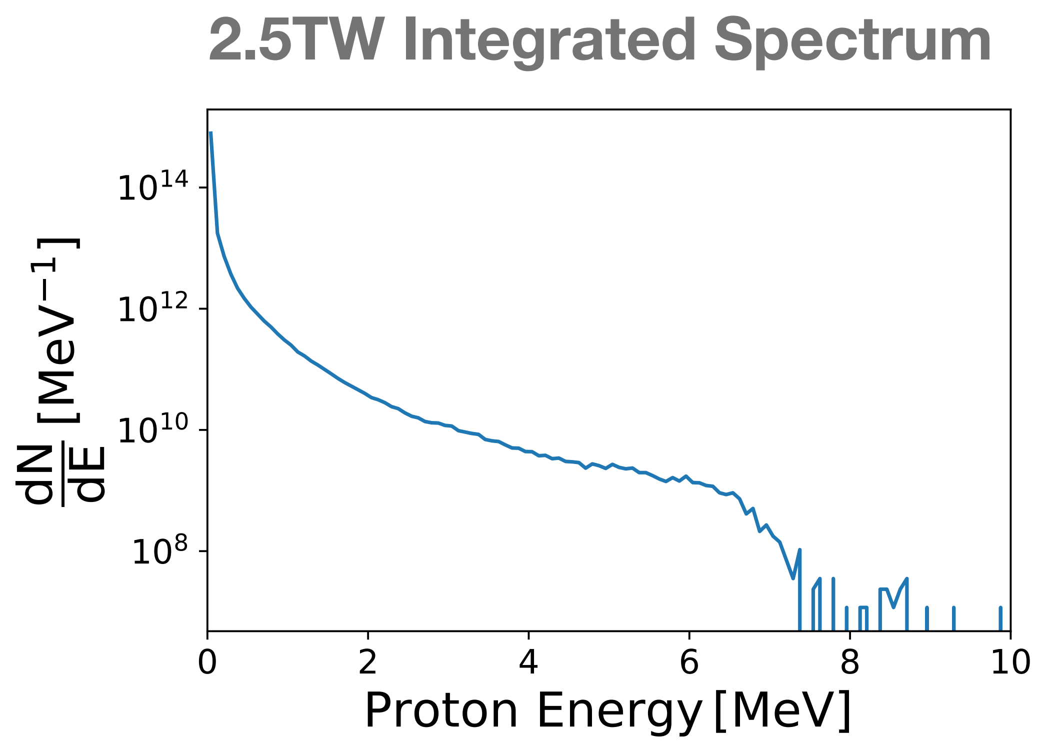
Recent Funding: EPSRC EP/N018680/1, EU Horizon 2020 No 894679

Experimental goals

Main proposal objectives for AE100

- Scaling of hole boring acceleration to higher intensities and shorter laser pulses
- Polarisation control of laser to critical density plasma coupling
- Direct observation of collisionless shocks
- Fundamentals of collisionless shocks and related laser-plasma interaction

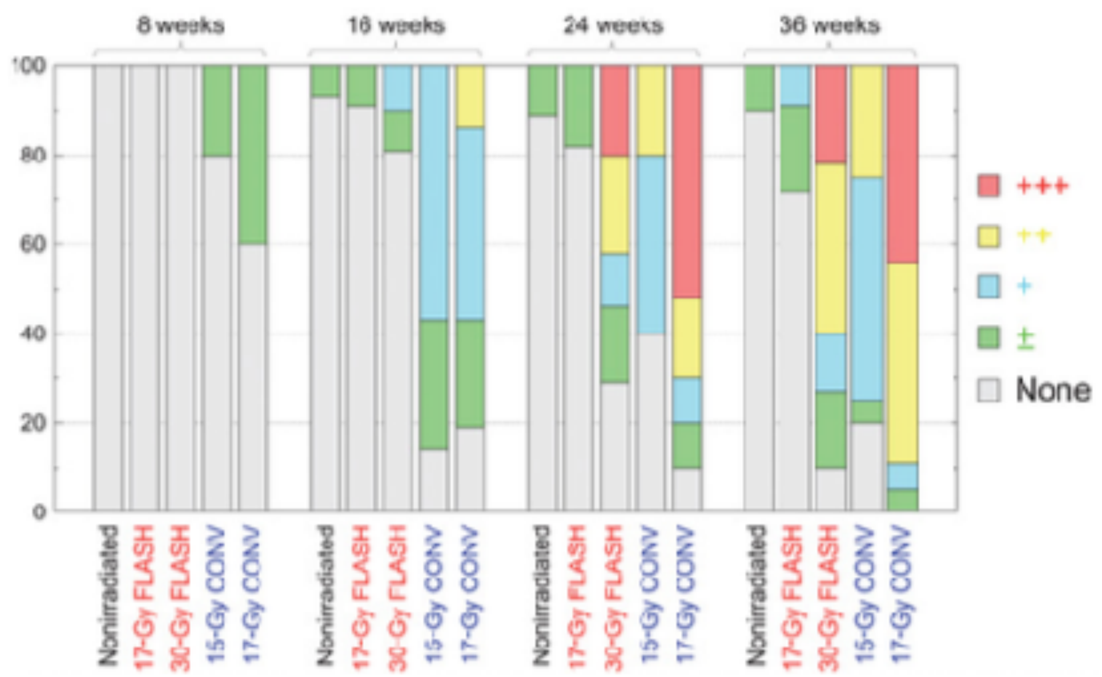


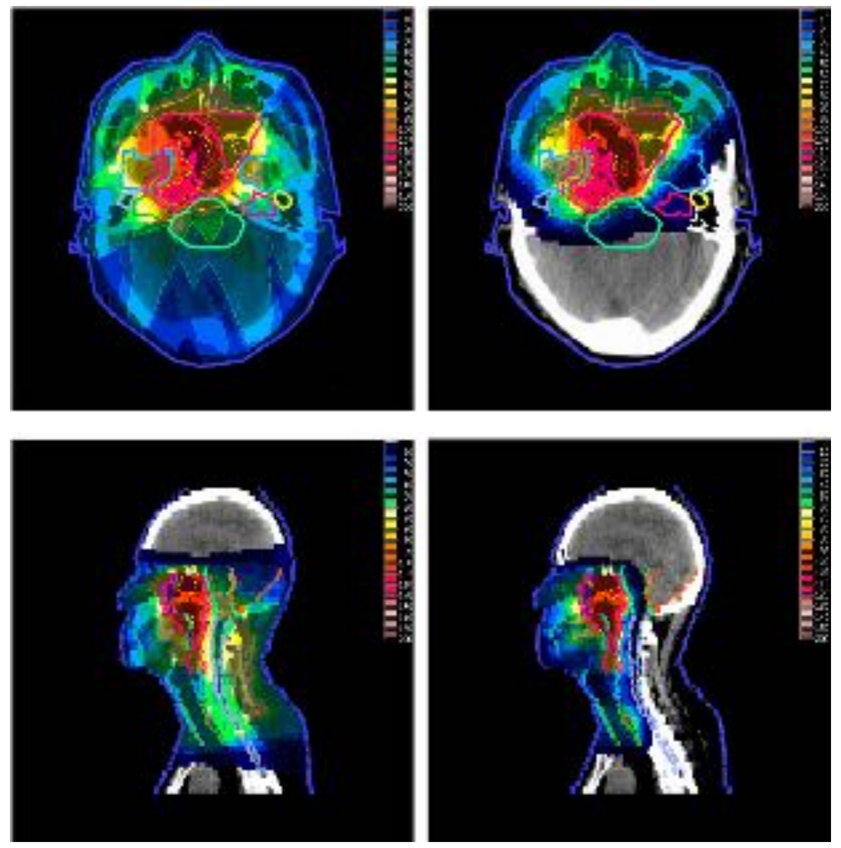


Experimental Overview (1)

Why laser driven ion sources?

Favaudon et al., Sci. Transl. Med. 6, 245 (2014)





*Z. Taheri-Kadkhoda et al. Radiation Oncology **3** (2008)*

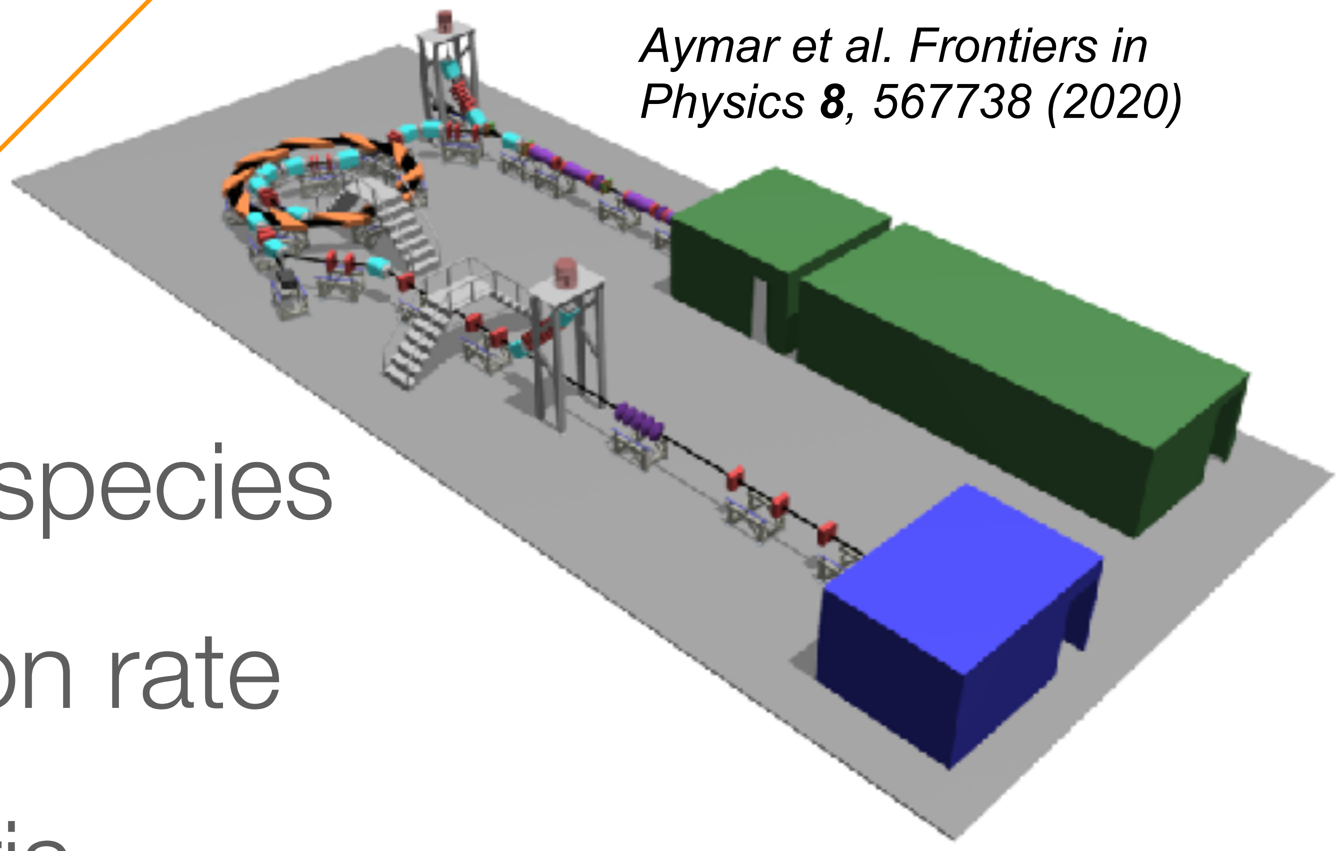
Laser driven ion sources increasingly attractive due to high source energy and short bunch length

For example, these sources are well suited for high dose rate radiobiology - e.g. FLASH

Important characteristics of laser driven source for applications

- High energy
- High flux
- Different ion species
- High repetition rate
- Minimal debris

*Aymar et al. Frontiers in Physics **8**, 567738 (2020)*



Gaseous targets are a great choice, if high energy, high flux ions can be produced…

Experimental Overview (2)

- In order to generate large static electric fields from EM fields, typically require:
  - Laser to be stopped by the plasma
  - Electrons need to gain significant energy to generate space charge

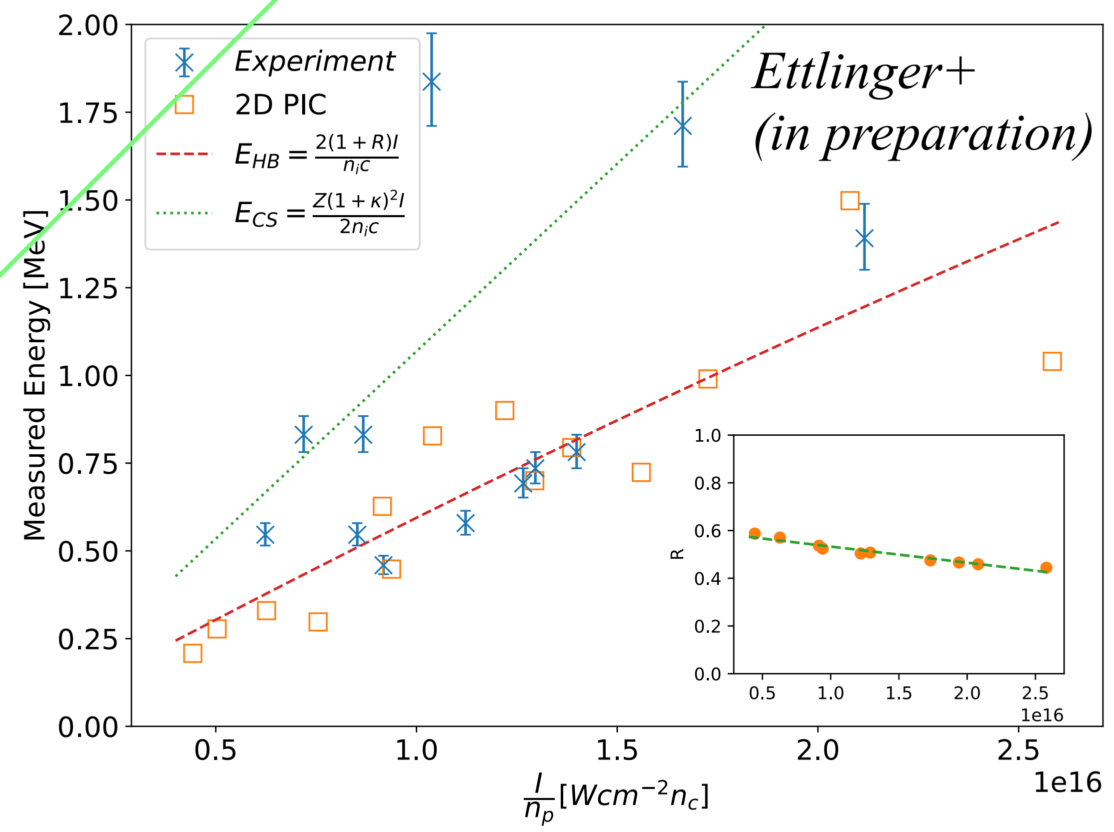
Critical density of a plasma scales favourably with wavelength

$$n_c = \gamma \frac{\epsilon_0 m_e}{e^2} \cdot \frac{4\pi^2 c^2}{\lambda^2}$$

Relativistic electron response scales favourably with laser wavelength

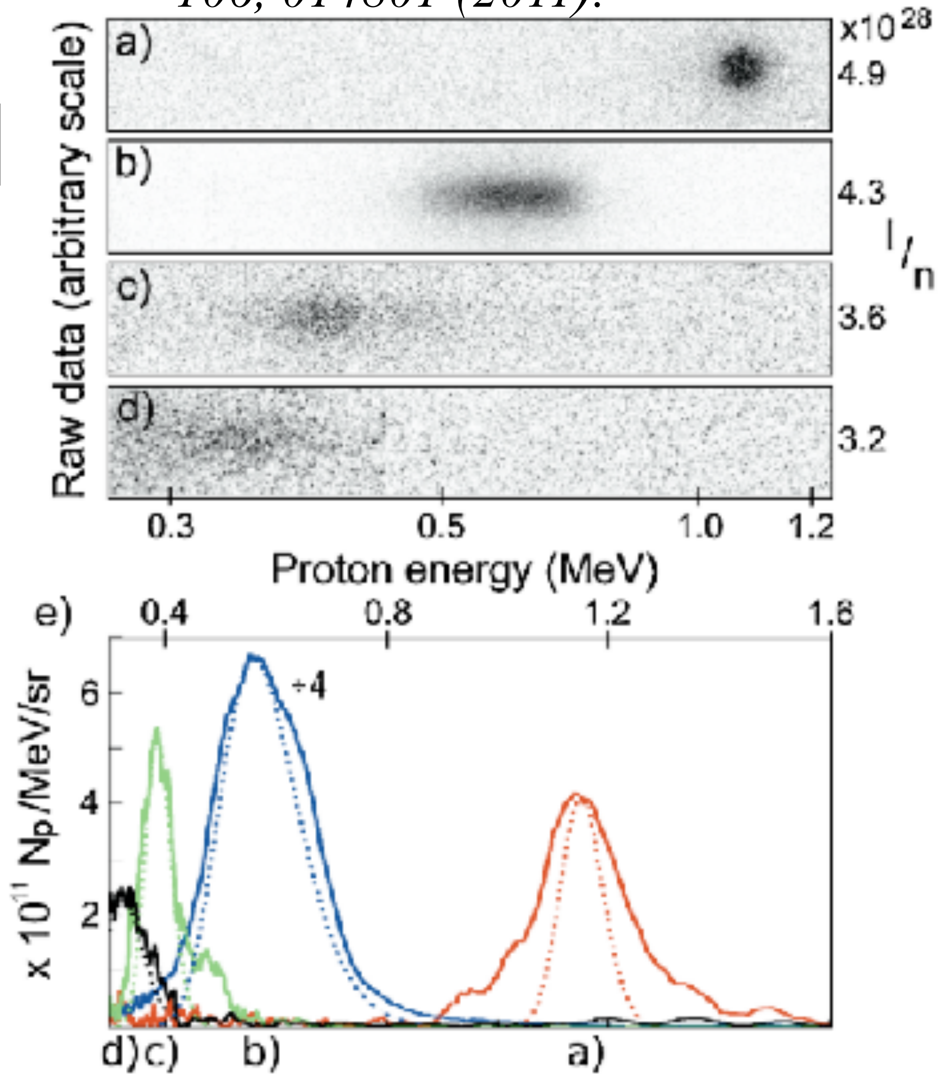
$$a_0 = \frac{eE_0}{m_e c} \cdot \frac{\lambda}{2\pi c}$$

The ATF's long wavelength high power CO_2 laser is ideal



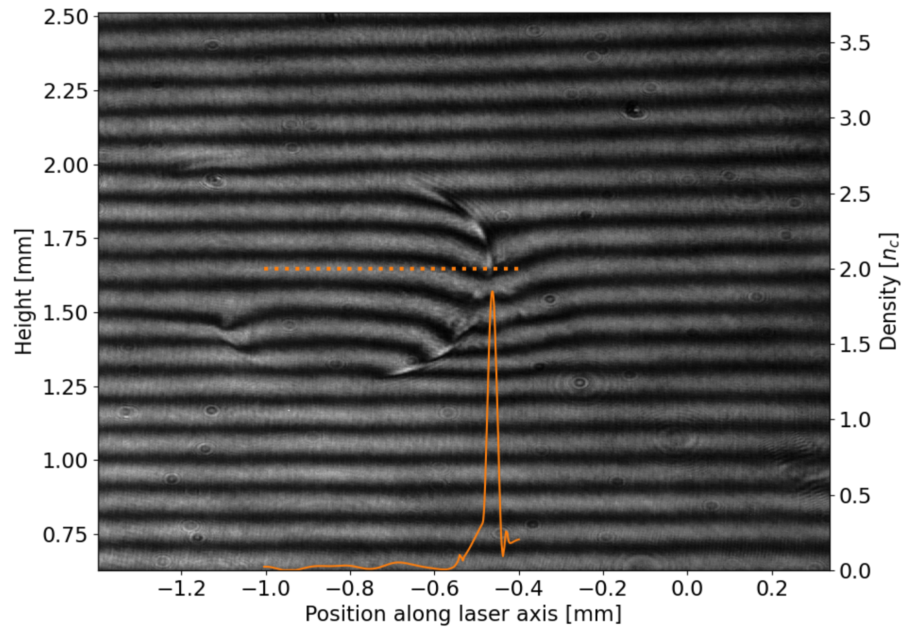
Ettlinger+ (in preparation)

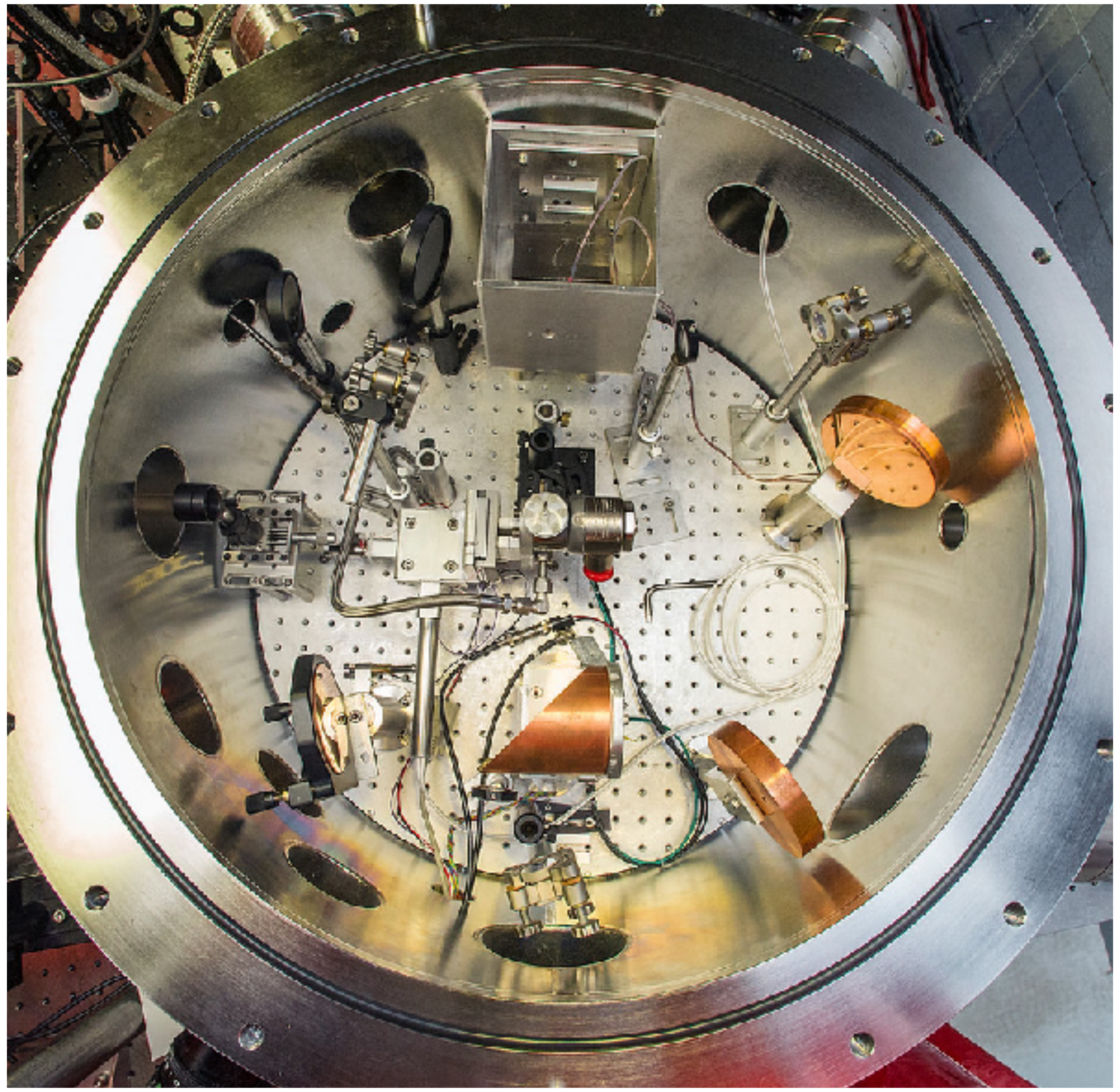
Palmer+, Phys. Rev. Lett. 106, 014801 (2011).

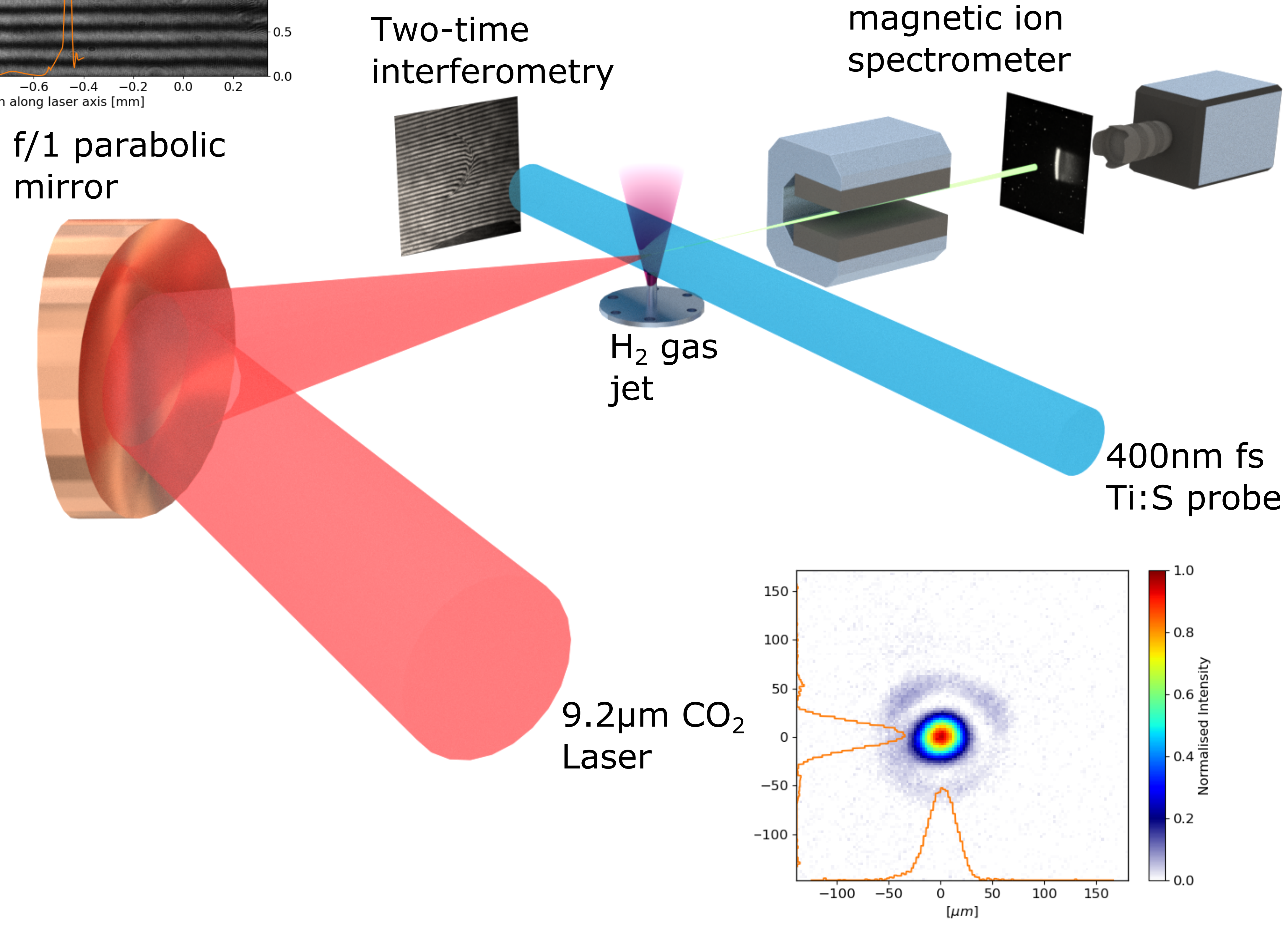


Experimental Overview (3)

mJ level laser pre-pulse to shape gas, optimising density profile - a “blast wave” - Tresca et al. PRL 115 (2015)





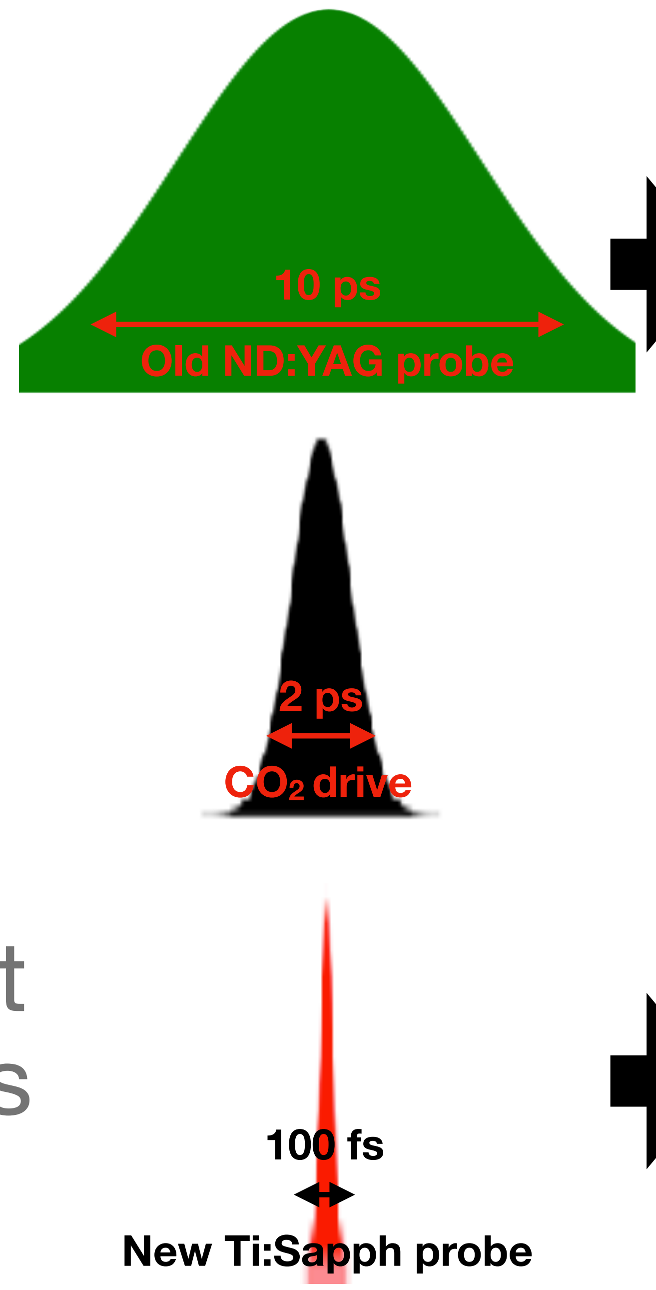


Summary of recent results

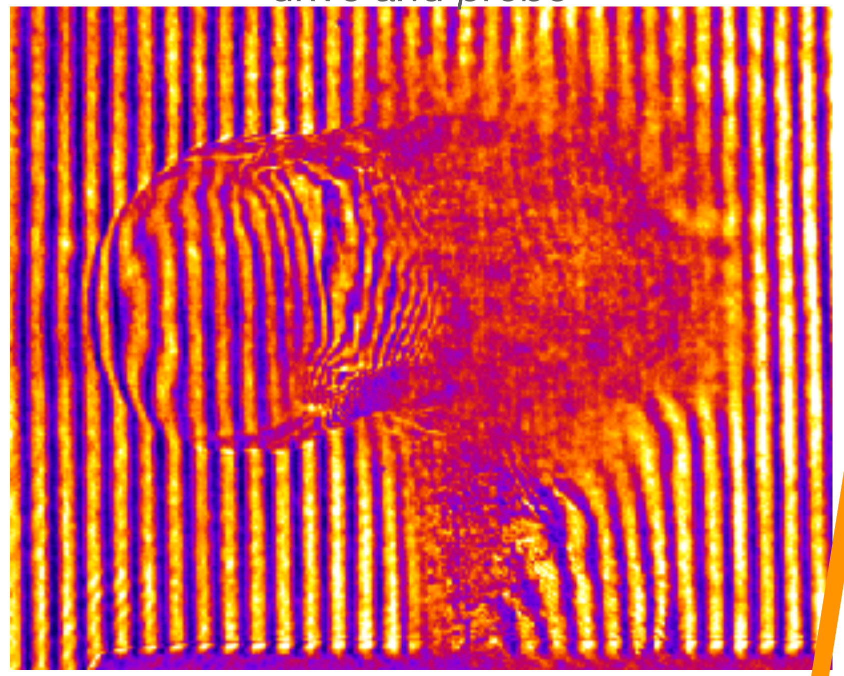
Achieved in the 2 week 2022 beamtime:

New femtosecond probe for measuring intrapulse dynamics

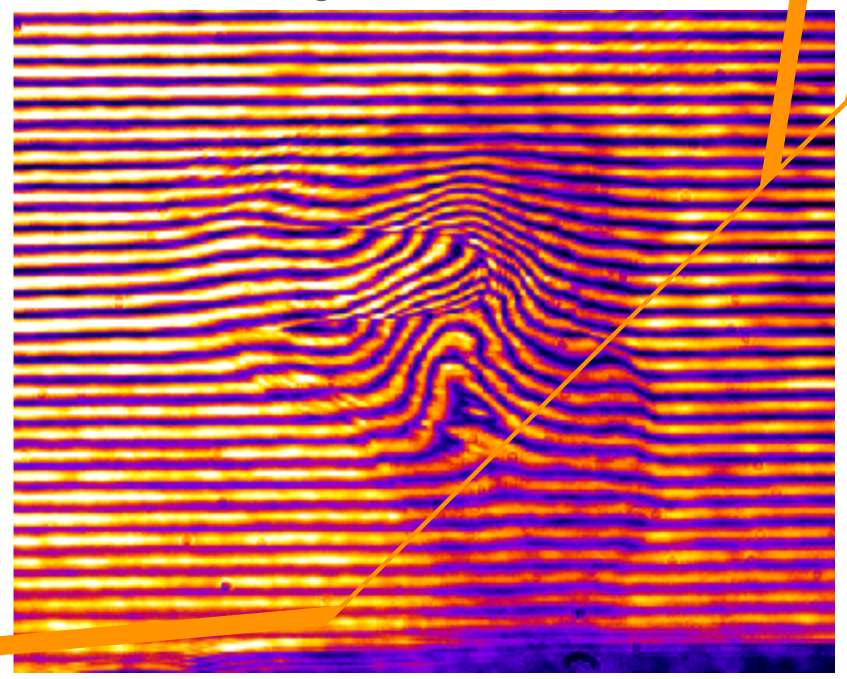
- Previously: 10 ps ND:YAG, results in significant image blur
- New in 2022: Implemented <100 fs Ti:Sapphire probe, allowing measurement of intrapulse dynamics



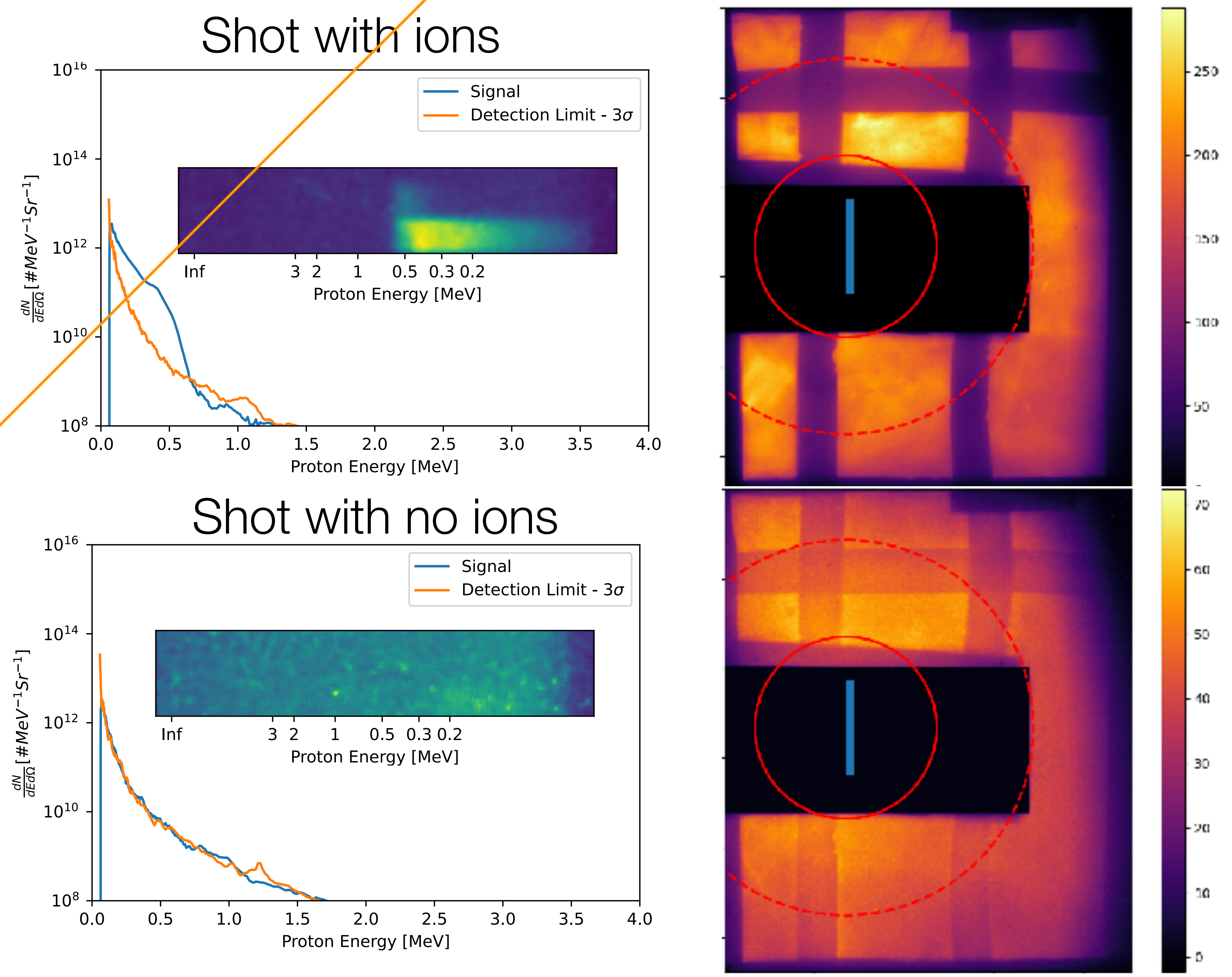
Previously: blur due to ionisation and plasma dynamics when temporal overlap between drive and probe



Now: clean images when overlapping drive and probe, allowing measurements of evolving overdense LPI



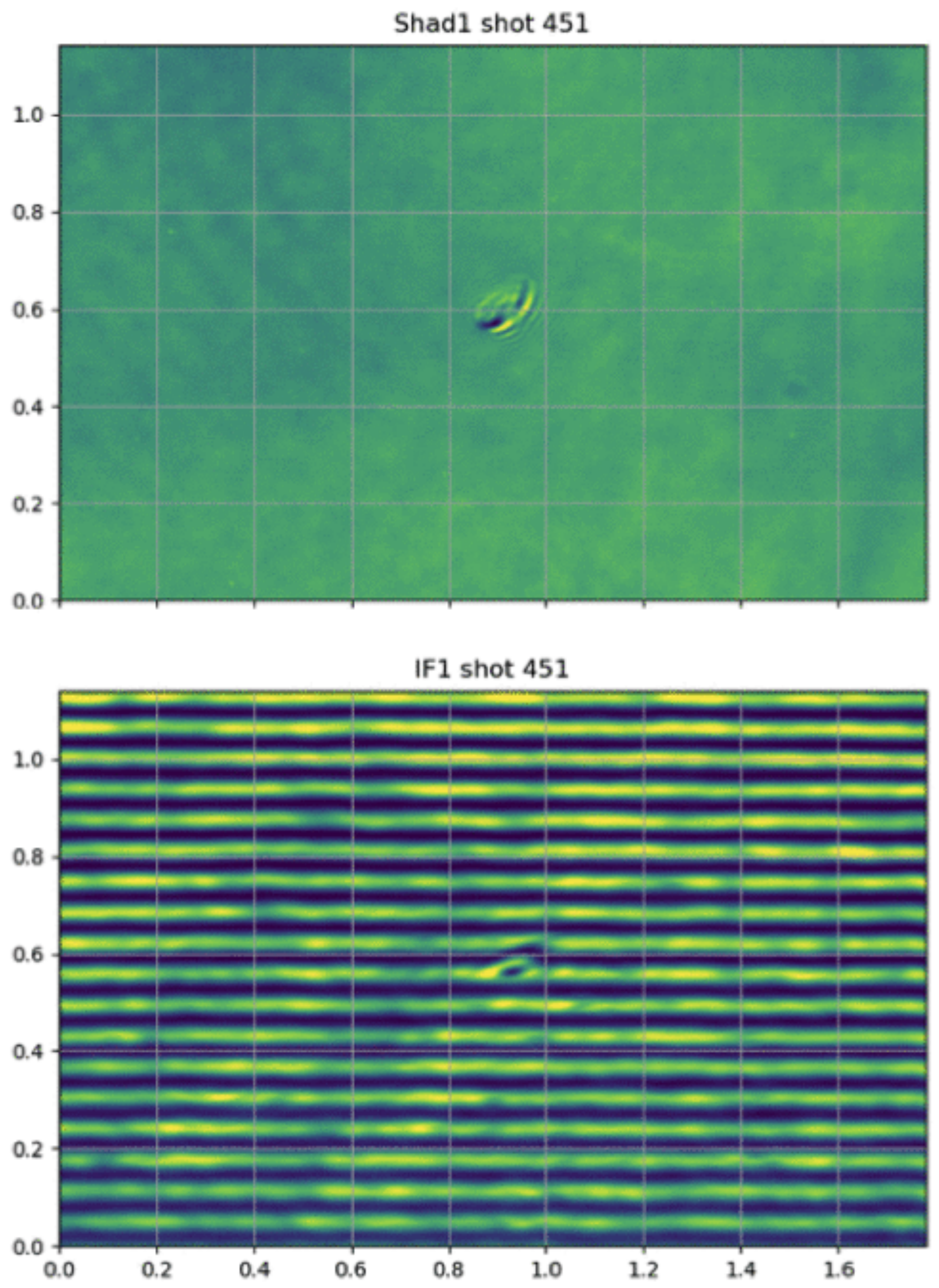
High repetition proton beam spatial profiler

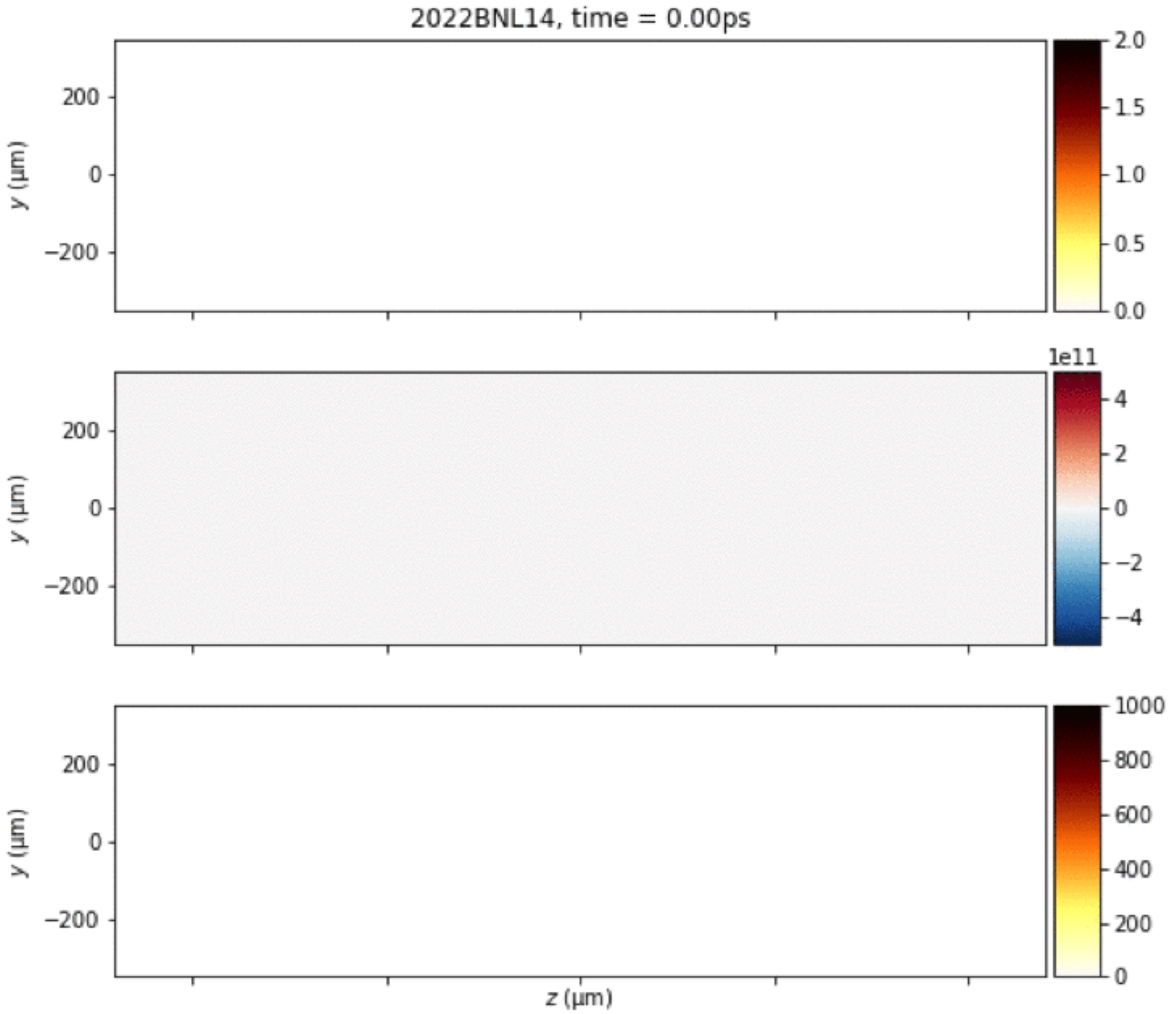


Summary of recent results

- Clear channeling of CO_2 pulse observed, coinciding with ion generation
  - Extremely stable ion generation, albeit low energy

t=-61 ps





Nick Dover, in preparation

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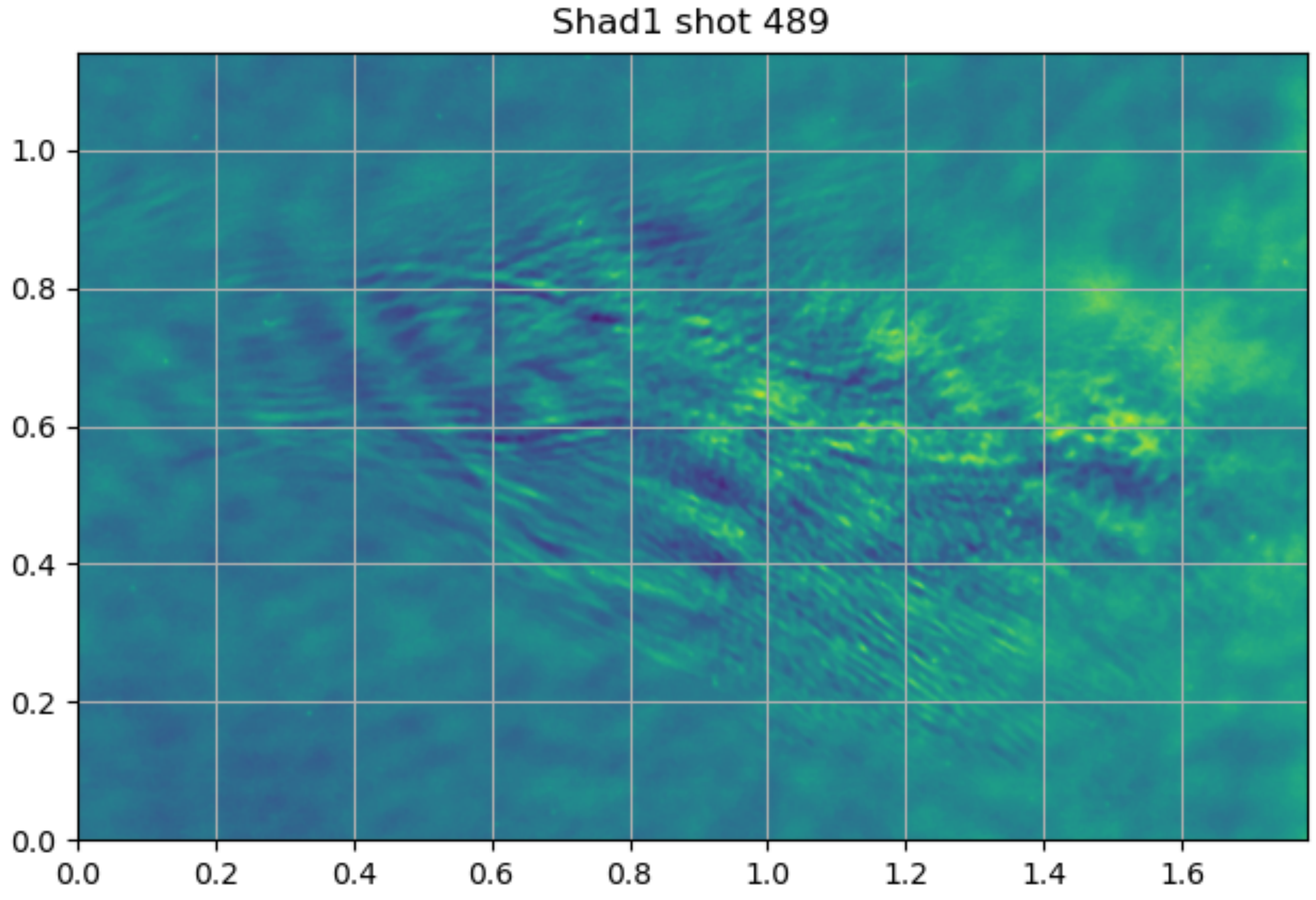
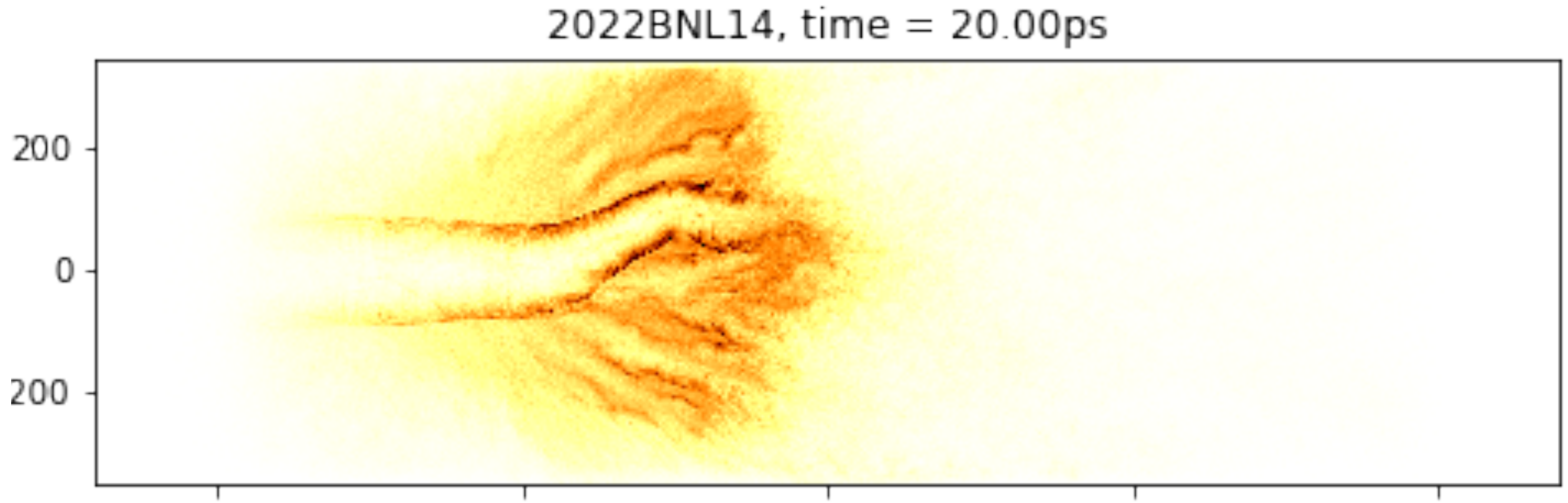




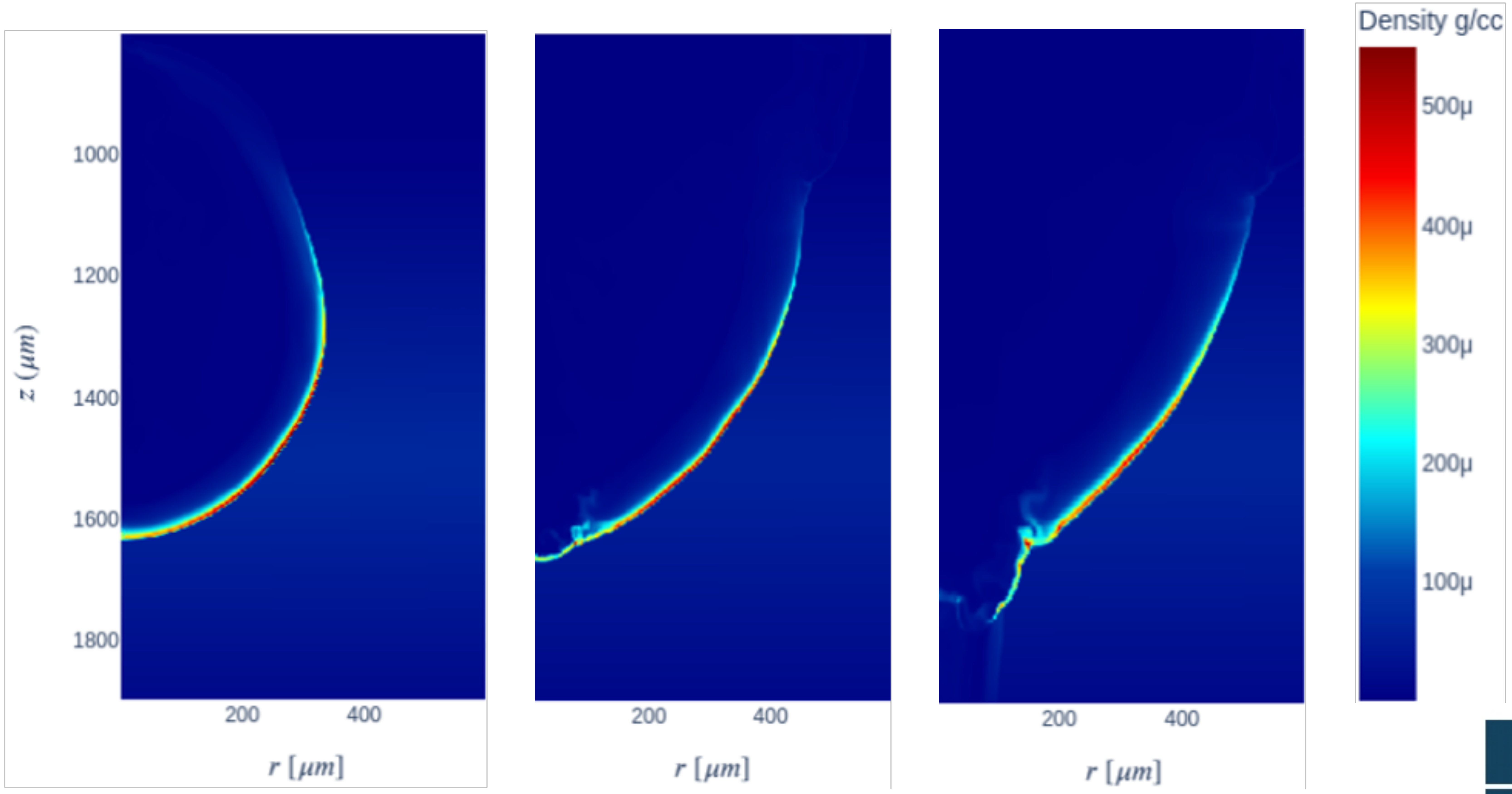
Good agreement with 2D PIC

Nick Dover, in preparation

Summary of recent results

- Acceleration behaviour due to a lack of appropriate target shaping
  - Larger f/# results in poorly formed blast waves

Plots courtesy of Matyas Rodriguez Szonyi

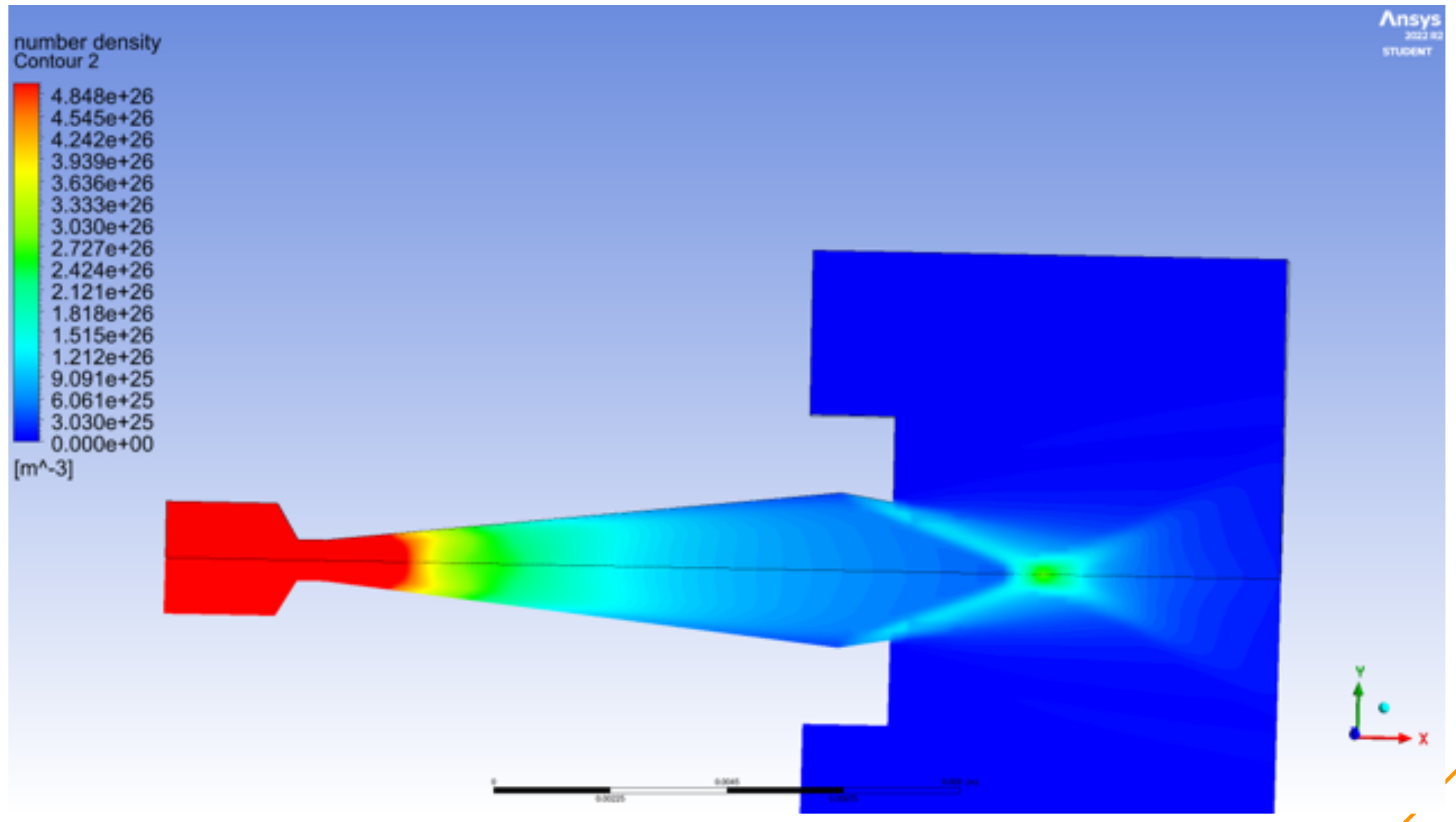


f/1 f/3 f/6

Other ongoing work

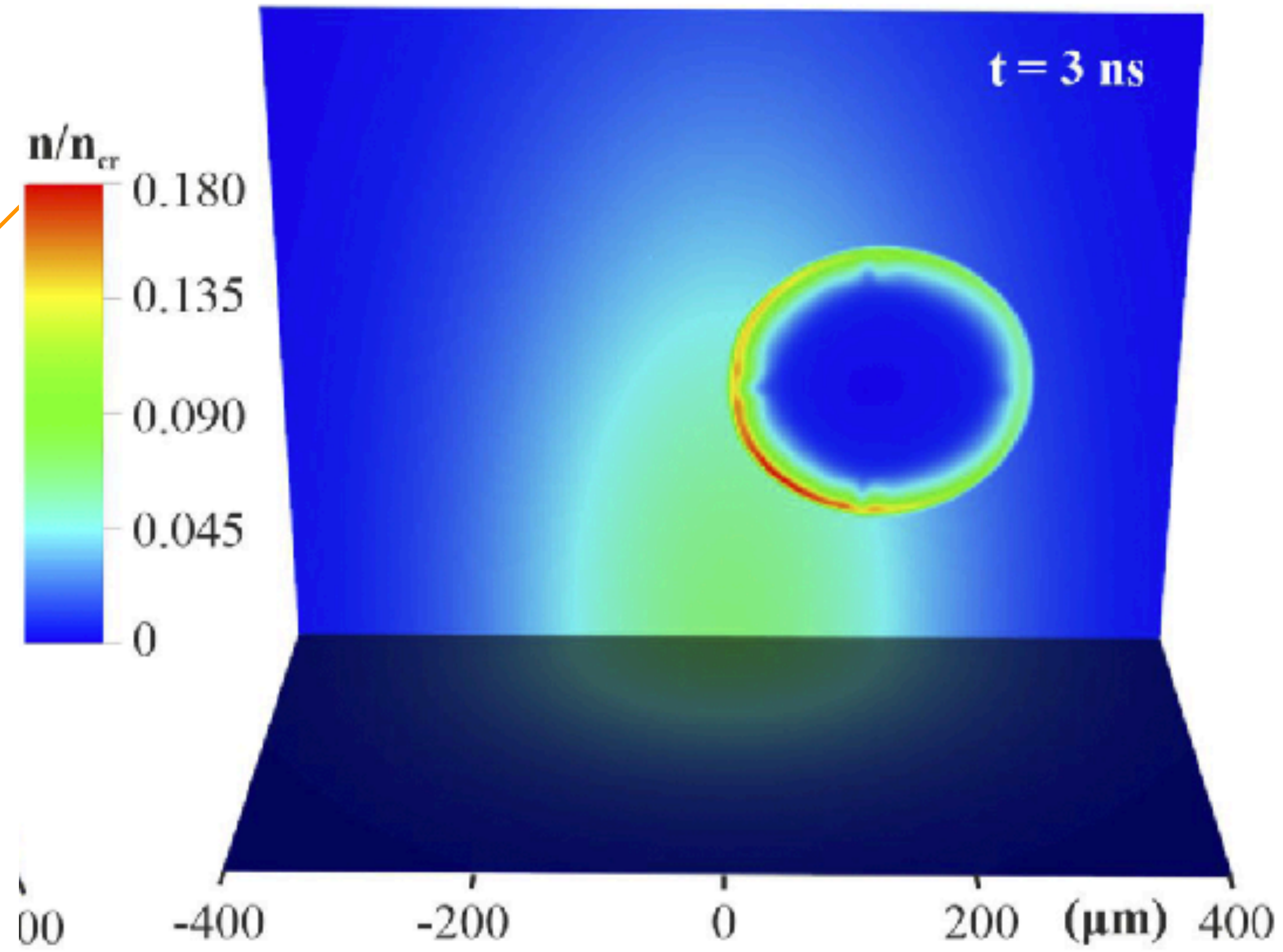
- Clear for a while that CO_2 pre-pulse is not the best way to achieve optimal target shaping conditions:

Simulations in ANSYS Fluent allow design of new, pre-shocked nozzles



work by PhD student, Ginevra Casati

Work by us and other groups to study the use of near-IR lasers for gas shaping



Tazes et al., HPLSE 2022

Plans for current experimental run

- In 2022, unable to generate hole-boring / shock acceleration
  - Blast wave from pre-pulse was unsuitable for generating steep density gradients on last experiment due to smaller effective f/# - should now be fixed
- Long term aim to shape target in a way decoupled from the CO_2 laser - plan to test new methods of target shaping
  - Shocked gas nozzles
  - Use YAG laser for gas shaping?
- Vary laser polarisation to optimise ion generation
- Use newly implemented diagnostics for characterisation of shockwave acceleration

Summary - AE100

- So far, 2-week beam times Feb 2020 and October 2022
  - New Ti:S probing capability transformational for understanding LPI
  - Exciting results on real-time imaging of channeling and ion acceleration in near-critical density plasma
- Current run aims to:
  - Address major issue with reliable blast-wave generation for density scale length shaping
  - Make direct measurements of hole-boring front
  - Investigate LP/CP effects on ion acceleration

John Adams Institute for Accelerator Science

Imperial College London

Activities & Impacts Associated with this Experiment – *All Years*

- **Recent talks:**
  - Invited talk, HEDS 2024 (Nick Dover)
  - AAC 2022 (Igor Pogorelsky)
- **Manuscripts:**
  - O. Ettlinger et al. (ICL) - “Proton acceleration from a near-critical density plasma grating” - in preparation
  - O. Ettlinger et al. (ICL) - “Experimental demonstration of shock-driven proton acceleration scaling at near-critical densities” - in preparation
  - N. Dover et al. (ICL) - “ Observation of laser-generated fast electron Weibel filaments” - in preparation
  - N Dover et al. (ICL) - “Direct observation of nonlinear laser propagation in near-critical density plasmas” - in preparation
  - S. Passaladis et al. - “Hydrodynamic computational modelling and simulations of collisional shock waves in gas jet targets“ HPLSE 8 (2020)

COVID-19 Impact

- **Please summarise any significant impacts from COVID-19 on your experiment and team through the course of your experiment**
  - Inability to complete any experiment from early 2020 through 2022 due to impact of pandemic, restricted travel etc.