John Adams Institute for Accelerator Science

Imperial College London

UNIVERSITY OF OXFORD

Royal Holloway University of London

A-SAIL

ADVANCED STRATEGIES FOR ACCELERATING IONS WITH LASERS

Ion acceleration from laser driven collisionless shockwaves in optically shaped gas targets

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http://www.adams-institute.ac.uk

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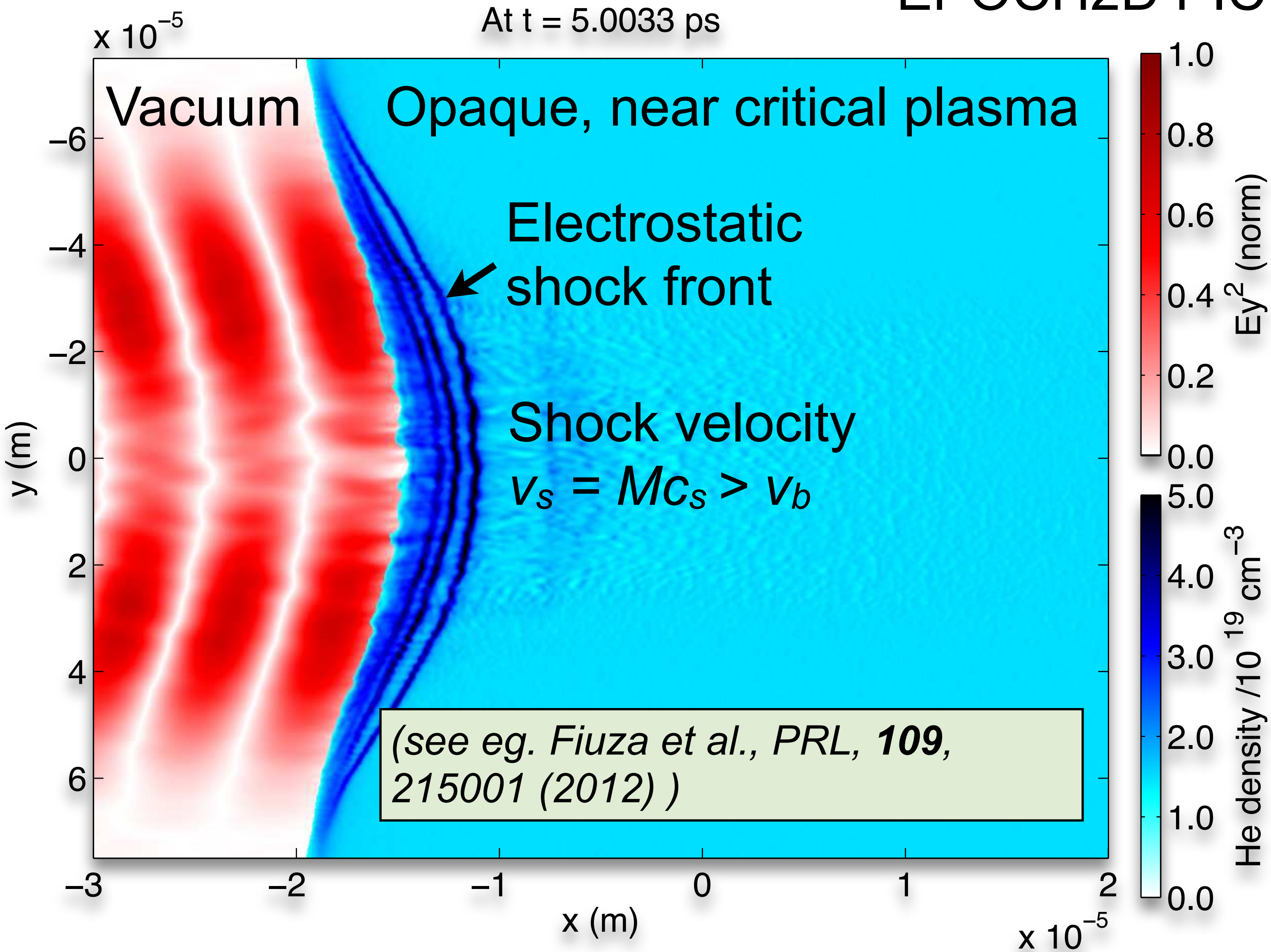
Accelerator Test Facility

O. Tresca, M.N. Polyanskiy, I.V. Pogorelsky

Ions accelerated from a moving shock

EPOCH2D PIC code



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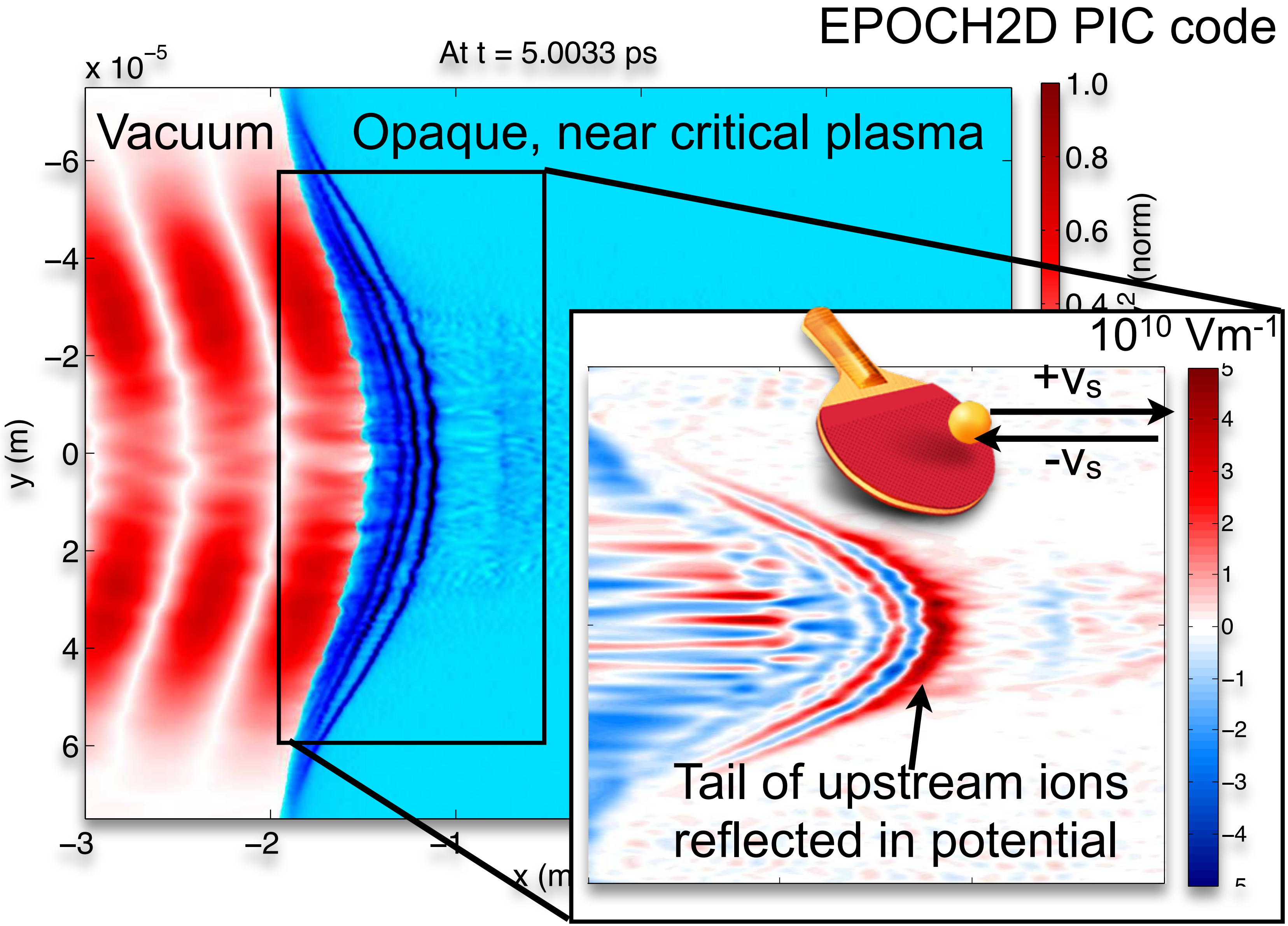
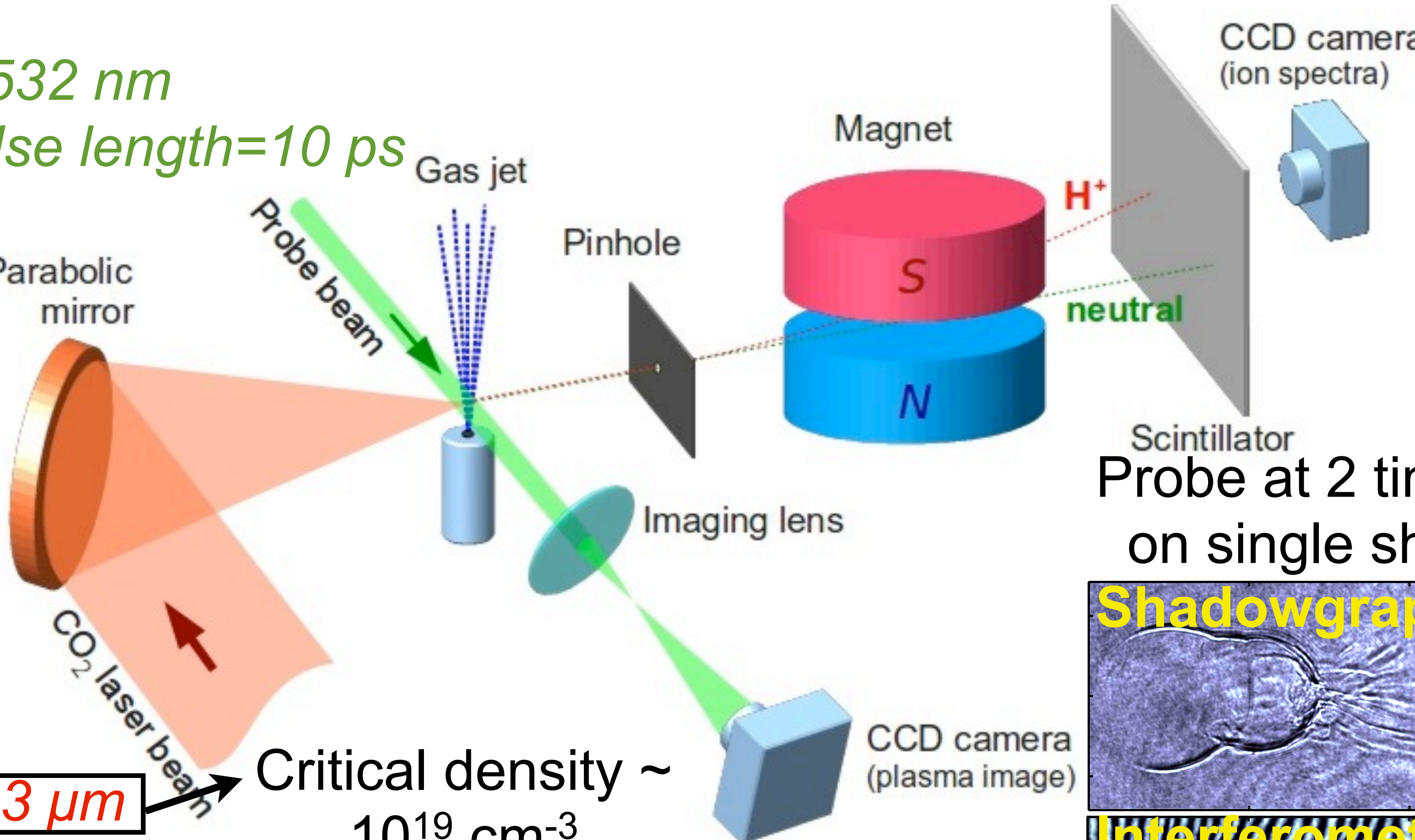


Typical experimental set-up

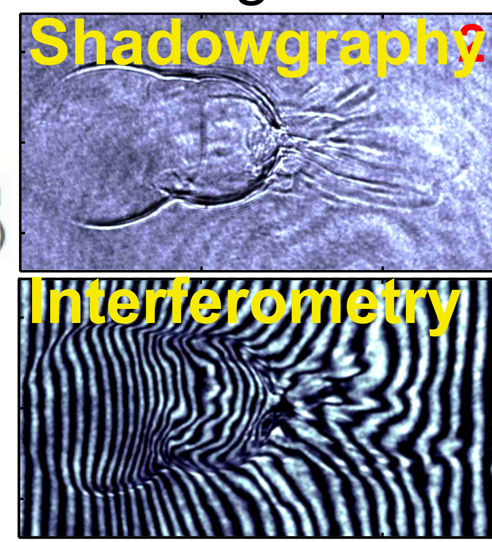
λ=532 nm
Pulse length=10 ps



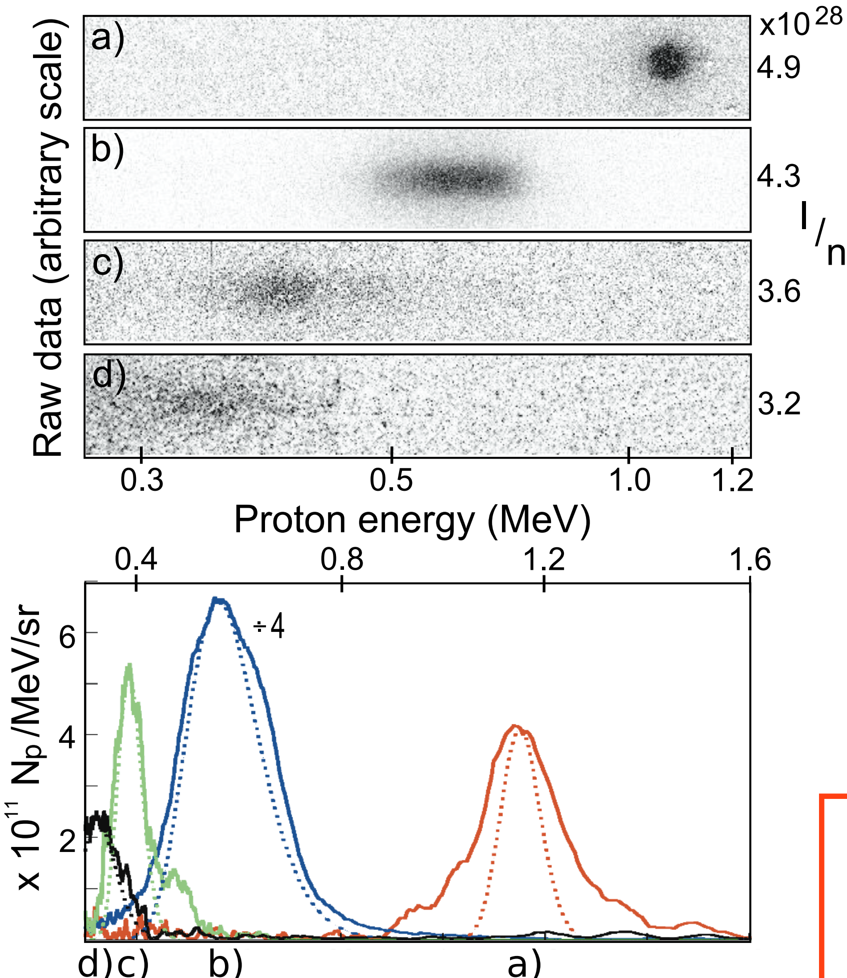
λ=10.3 μm
Pulse length ~ 5 ps
Spot size = 70 μm
Intensity ~ 10^{16} W/cm^2

Critical density ~ 10^{19} cm^{-3}

Probe at 2 times on single shot



First results: monoenergetic protons

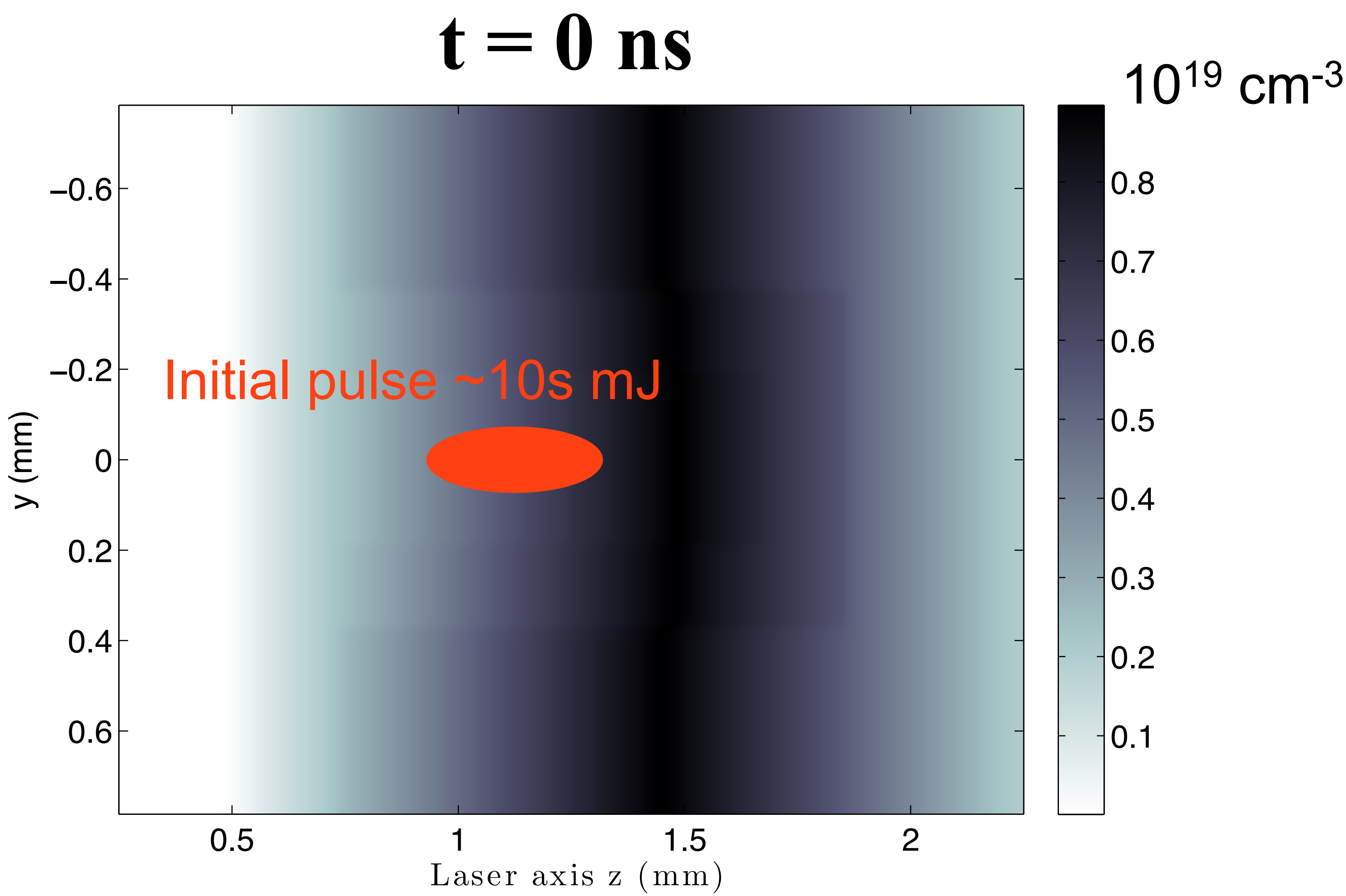


*Above from Palmer, Dover, Pogorelsky et al., PRL, **106** (2011)*

- CO_2 experiments with gas jets showed >MeV spectrally peaked proton beams
  - Palmer *et al.* PRL **106** (2011)
    - ATF laser, ~1 J, a_0 ~1
    - E ~ 1 MeV, ΔE/E ~ 4%
    - ~10^{10}-10^{11} protons/MeV/sr
  - Haberberger *et al.* Nat. Phys. **8** (2012)
    - Neptune laser, ~60 J, a_0 ~ 2
    - E ~ 20 MeV, ΔE/E < 1%
    - ~10^7 protons/MeV/sr

- Both experiments relied on pulse train from CO_2 laser to modulate density profile
- *Pulse train can be unpredictable!*

Hydrodynamically shaping a gas target



FLASH (hydro)

Hydrodynamically shaping a gas target

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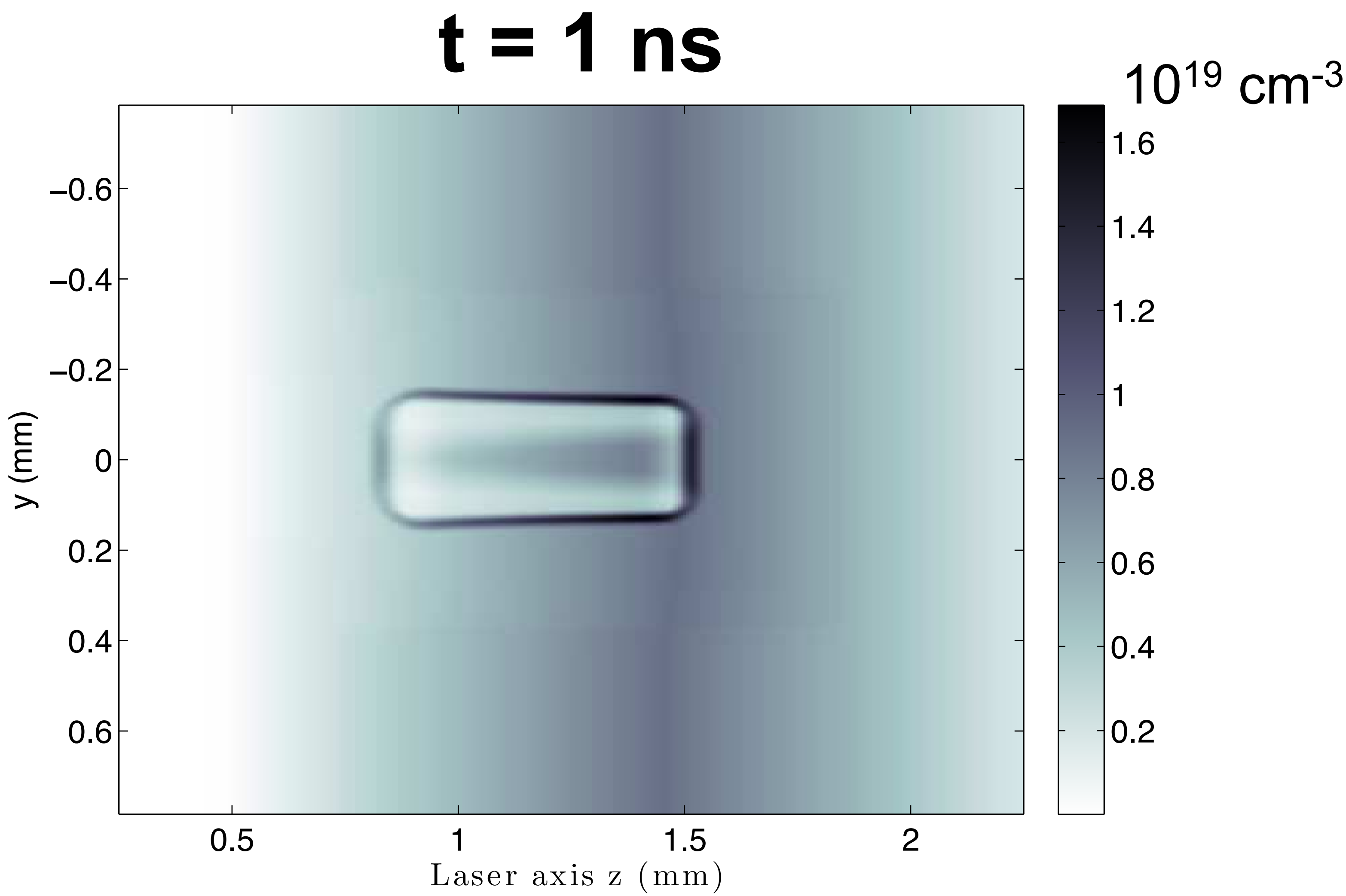
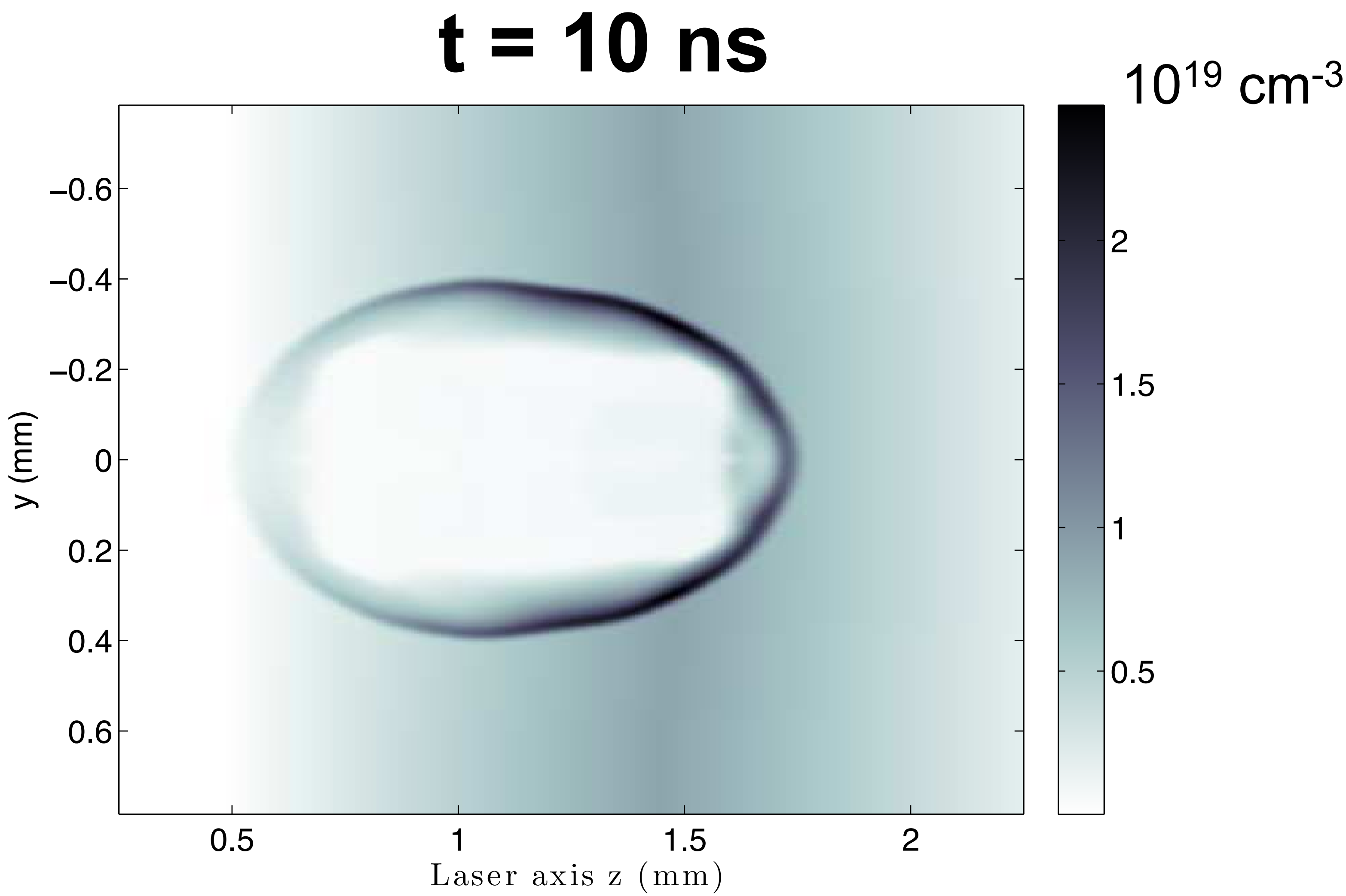


FLASH (hydro)

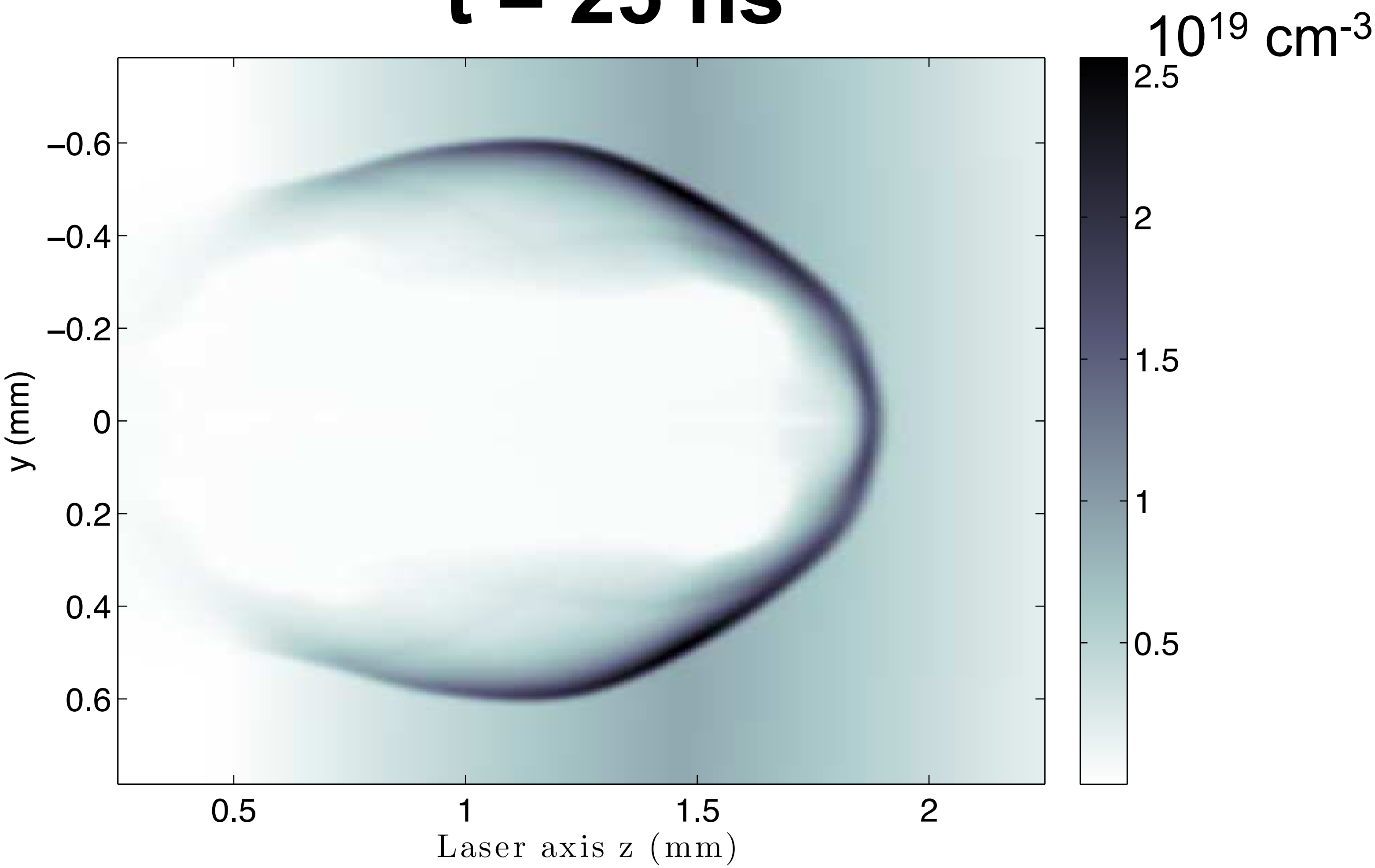
Hydrodynamically shaping a gas target



FLASH (hydro)

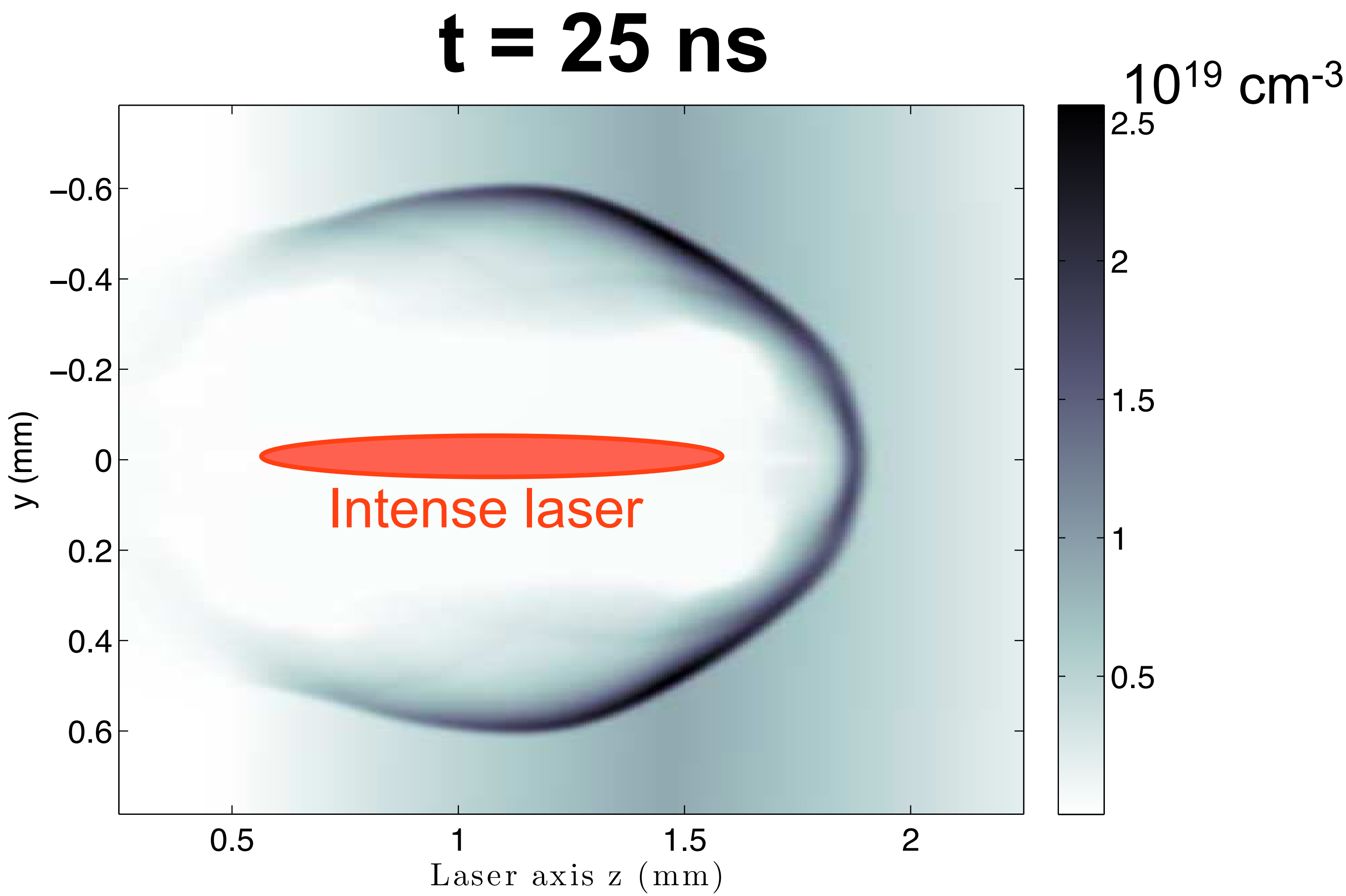
Hydrodynamically shaping a gas target

t = 25 ns



FLASH (hydro)

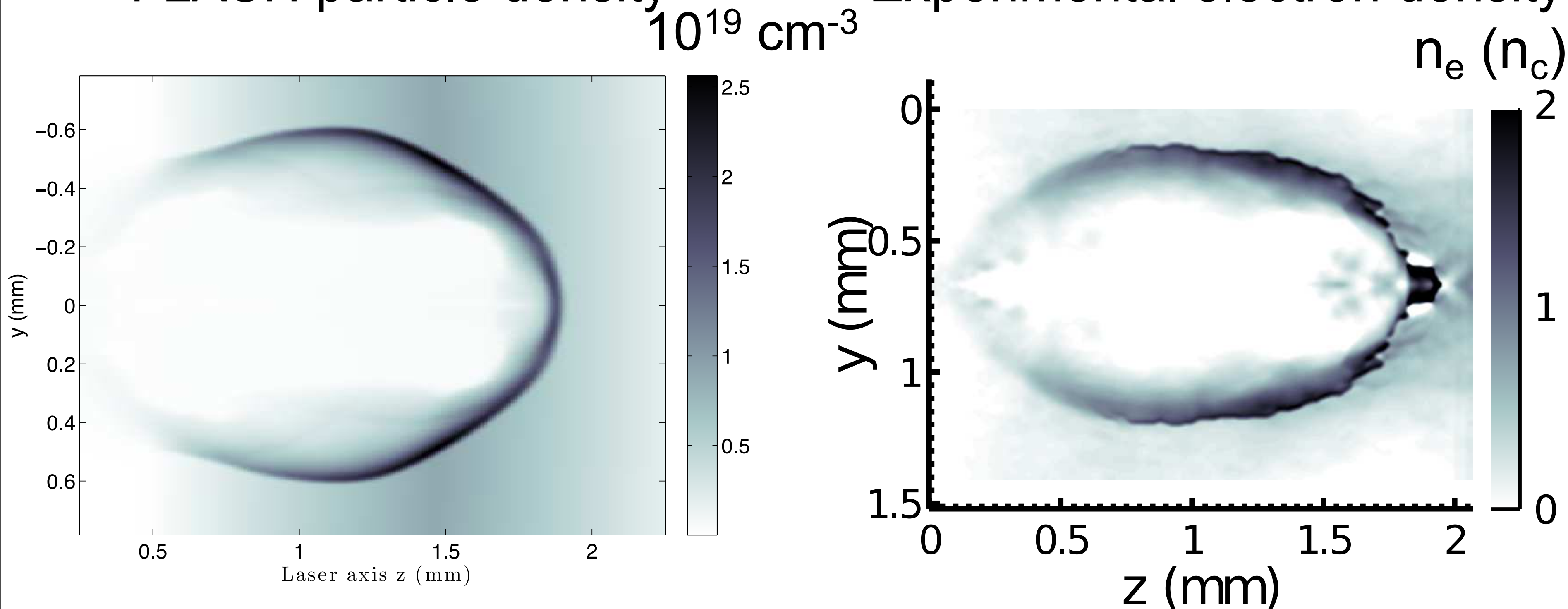
Hydrodynamically shaping a gas target



FLASH (hydro)

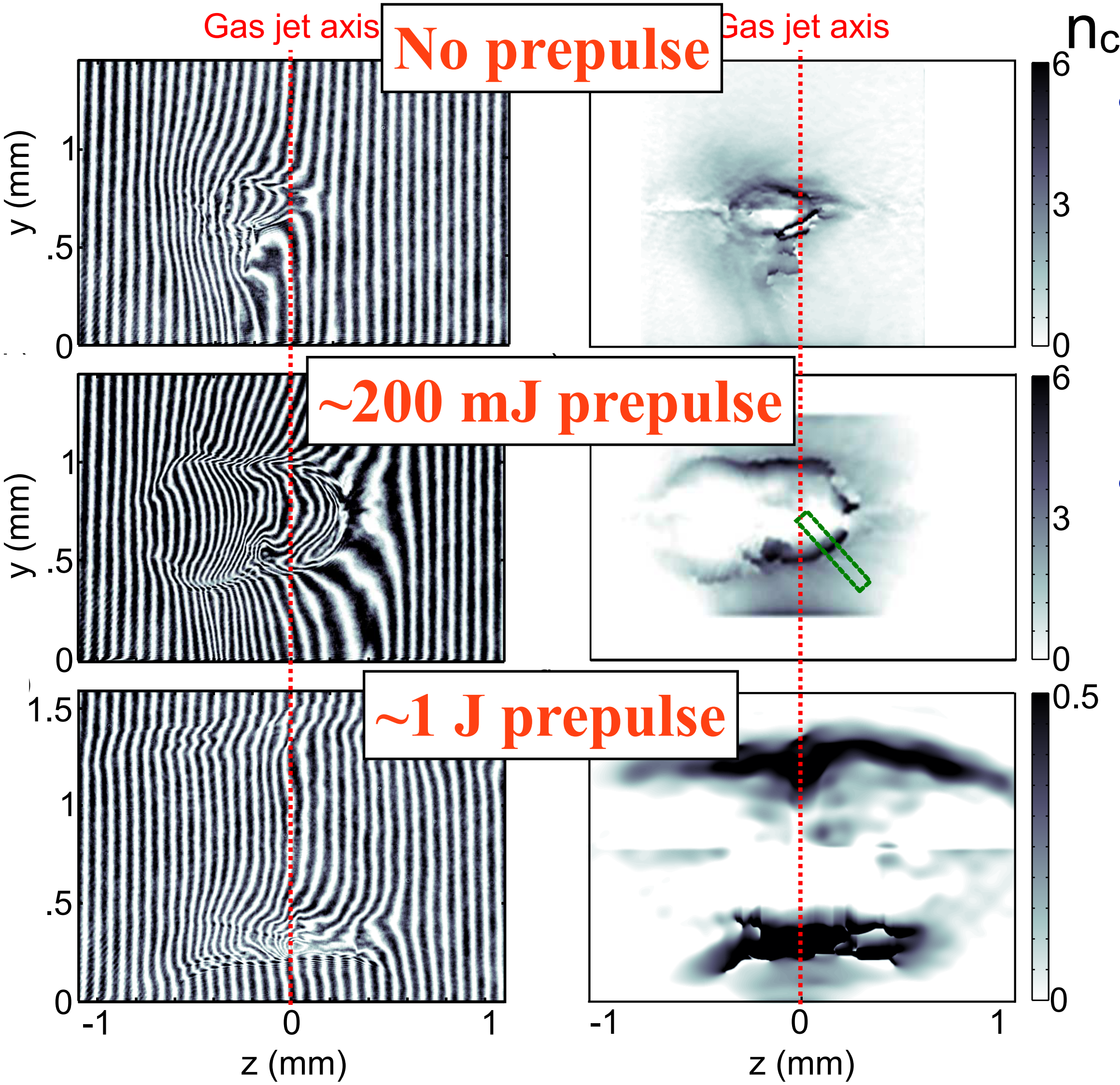
Hydrodynamically shaping a gas target

FLASH particle density | Experimental electron density



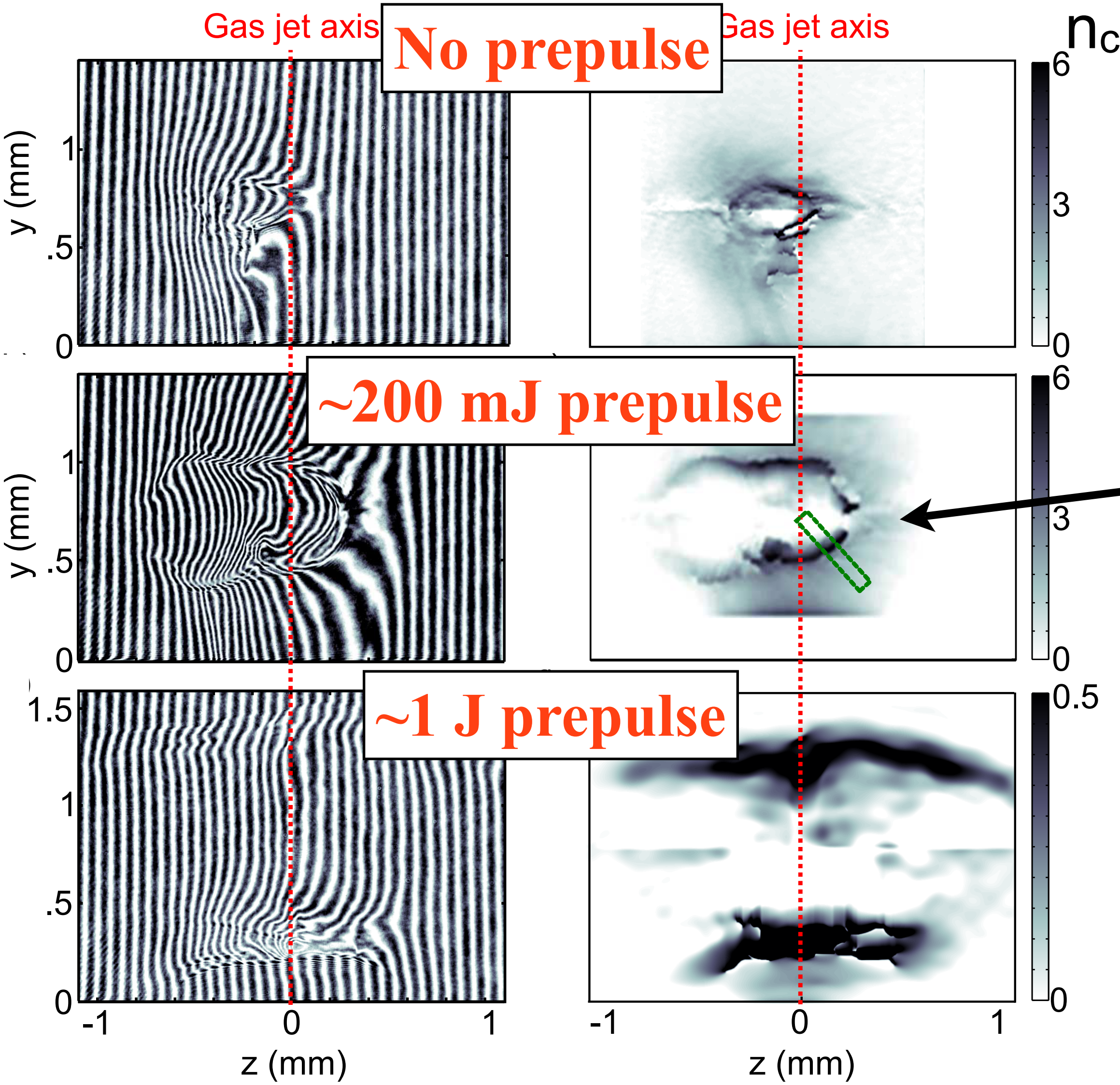
Probing after intense pulse LPI shows good agreement between experiment and modelling

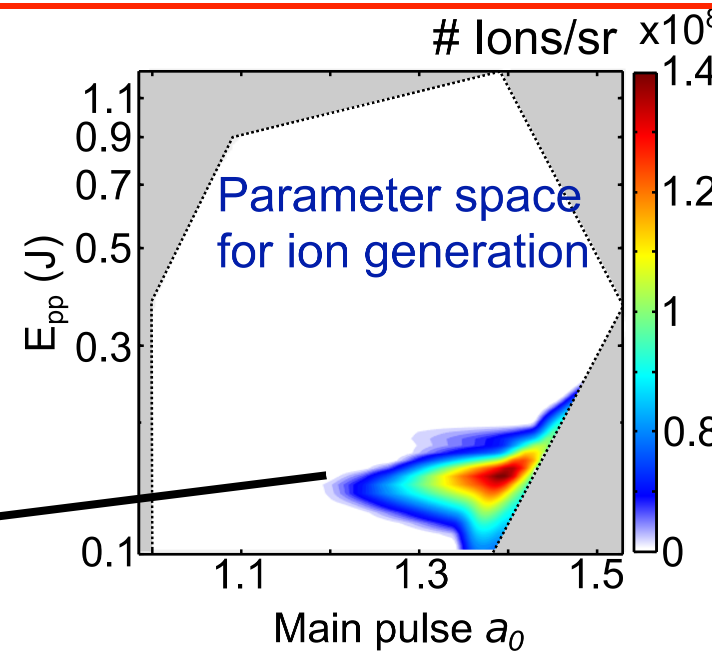
Effect of prepulse in helium

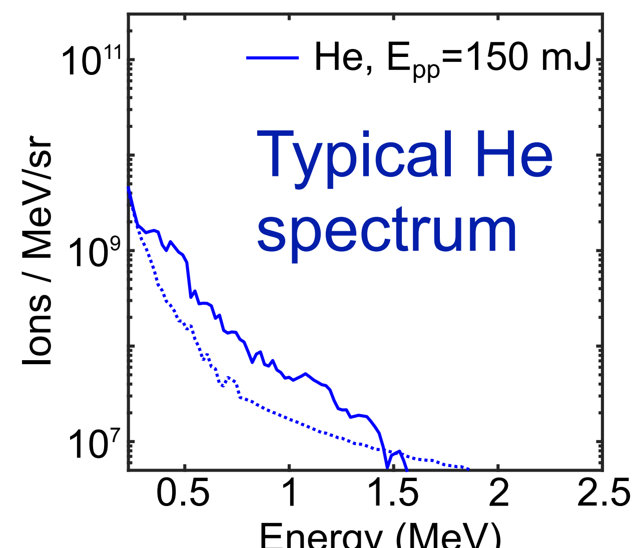


- Using ~100 mJ prepulse generates ~10λ density ramp for main pulse to interact with
- Sharp density ramp allows efficient *localised* heating & shock generation

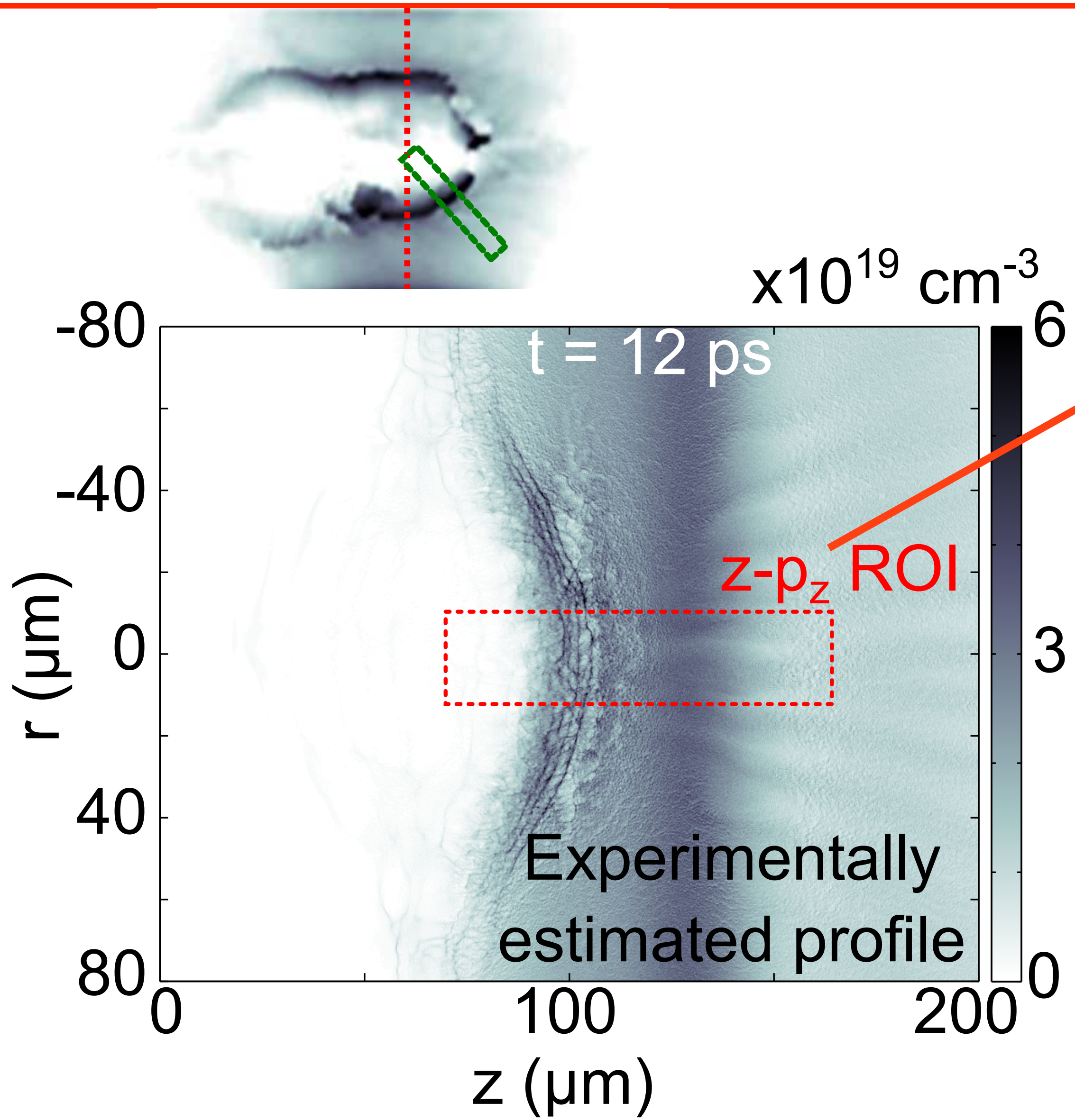
Effect of prepulse

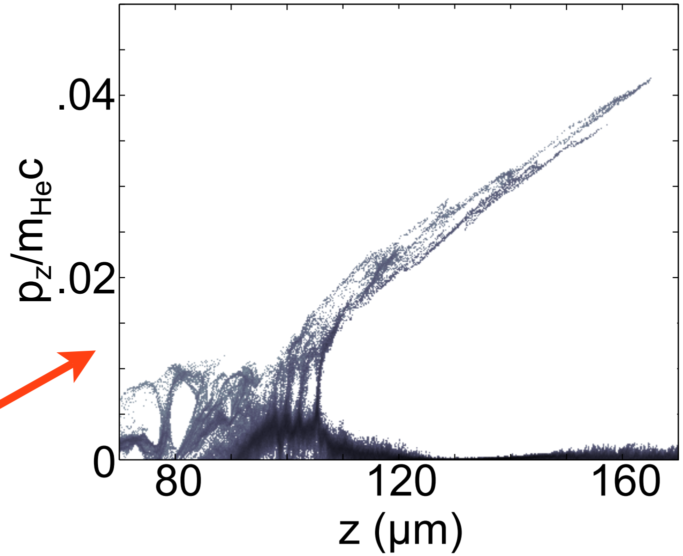


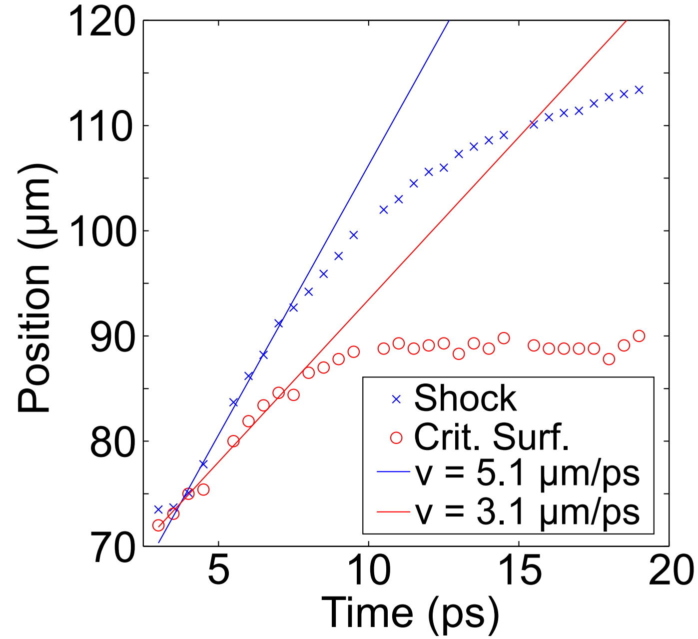




PIC agrees and predicts upstream effects

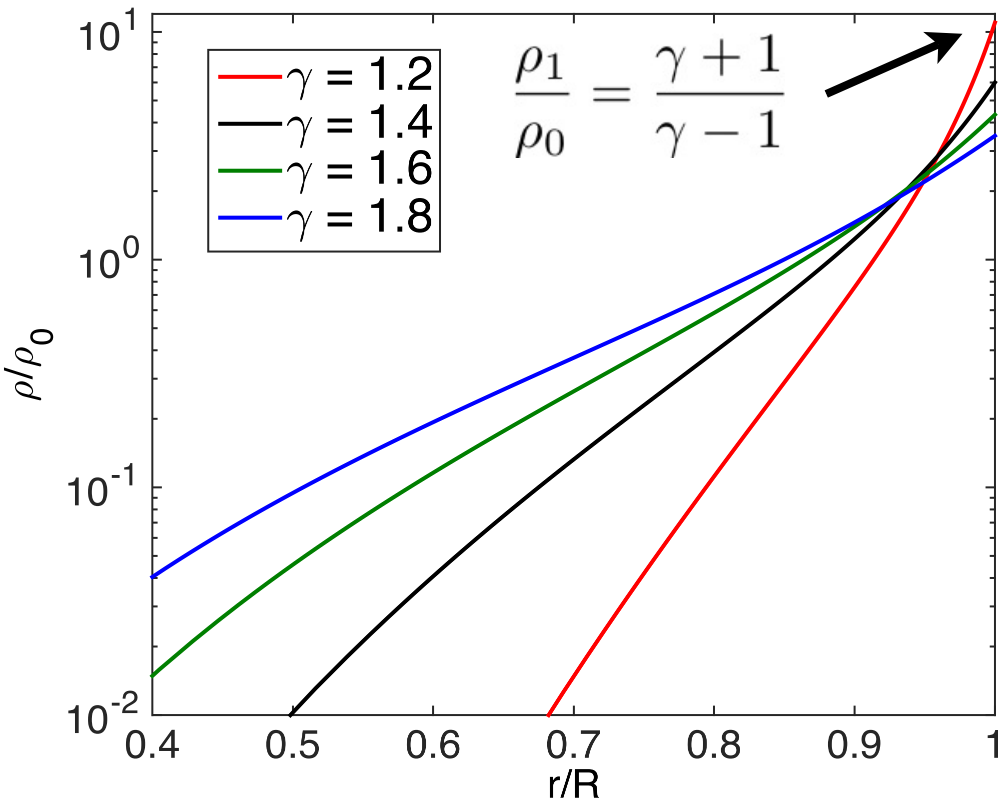


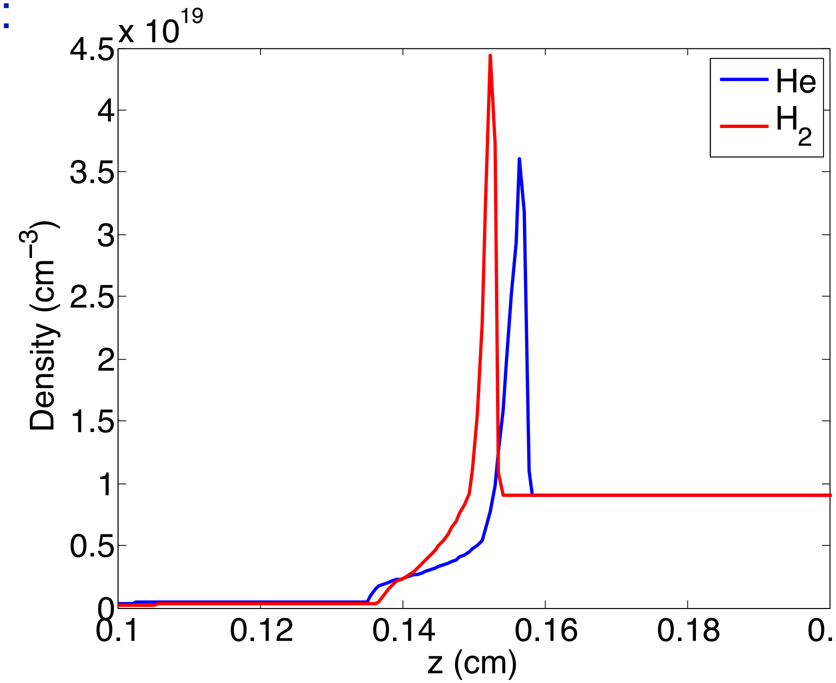




Switching to hydrogen gas steepens gradient

Self-similar radial blast wave density profile:





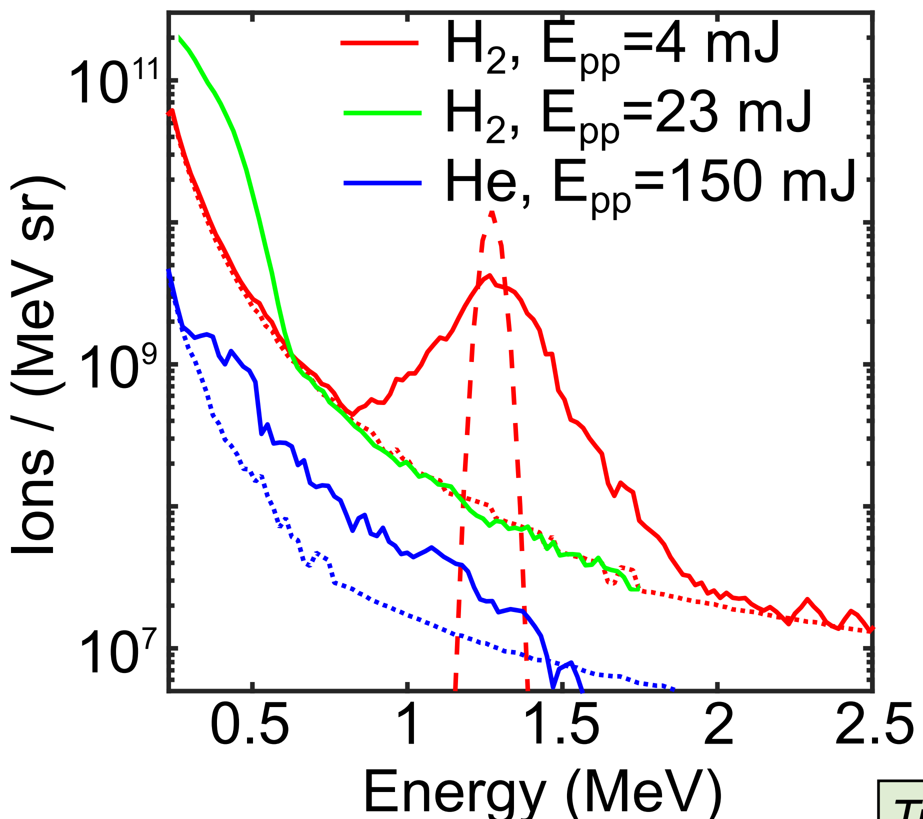
(see eg. Sedov, Similarity and Dimensional Methods in Mechanics, 1959)

Switching to hydrogen for a given blast wave radius gives a *sharper* gradient

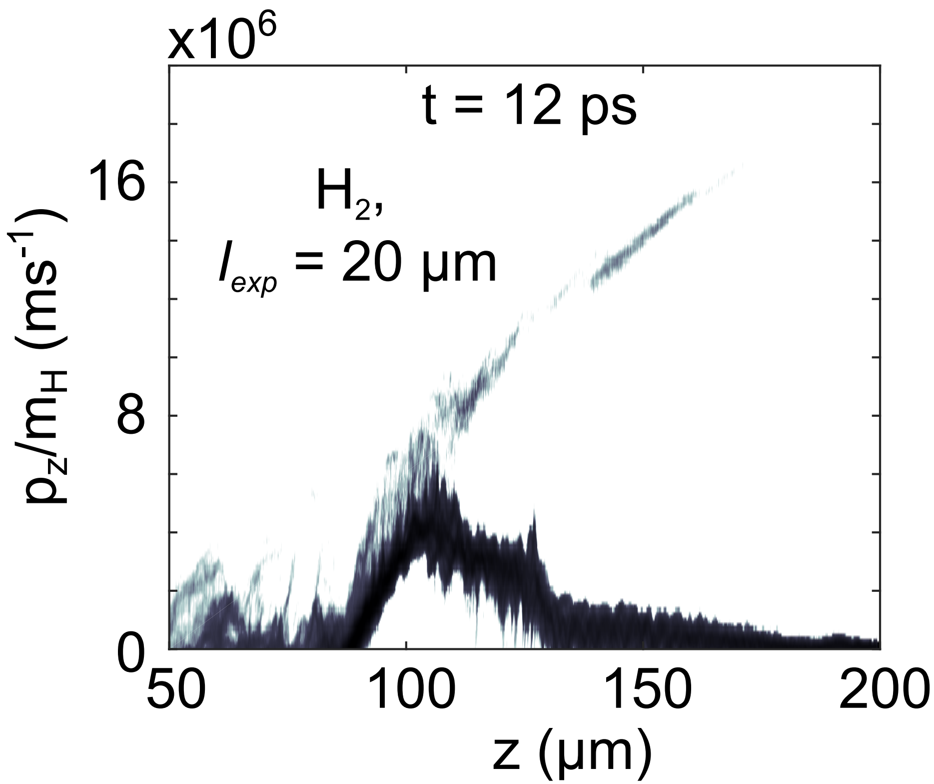
Using a smaller (but developed!) blast-wave will also give shorter gradients

Quasi-monoenergetic beams with hydrogen

When switching to hydrogen gas, for right prepulse level quasi-monoenergetic beams are generated:



EPOCH2D PIC code:

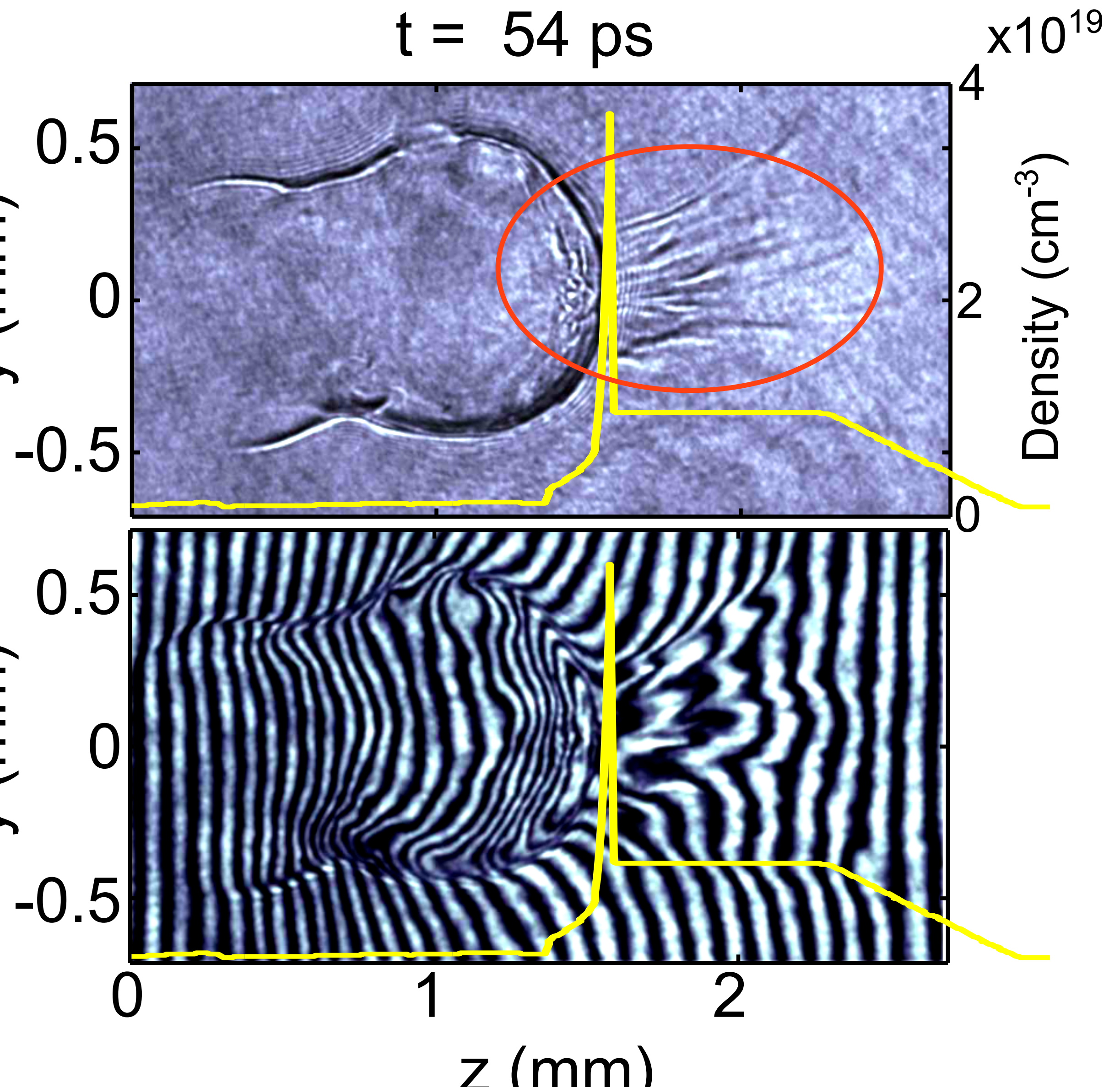


Shock dissipates as it passes through the blast wave, leaving a narrow band bunch

Tresca, Dover et al., PRL ***115*** *094802 (2015)*

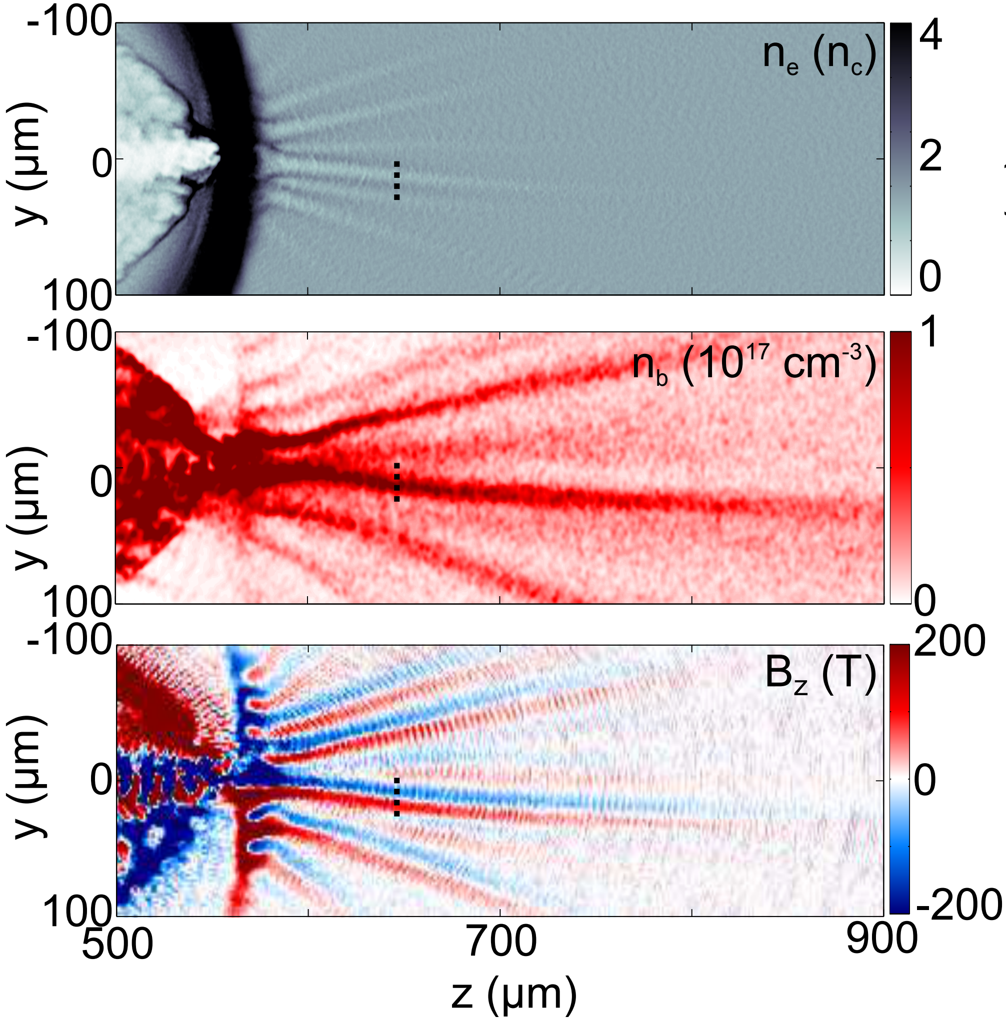
Observation of filamentation inside plasma

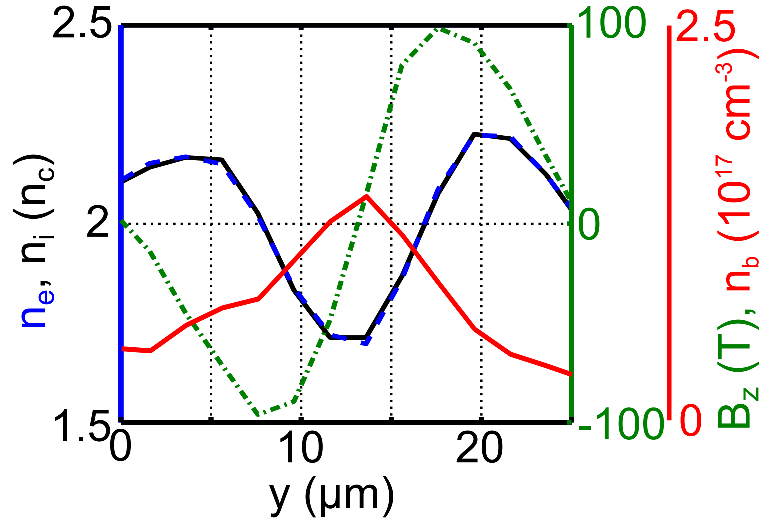
- Using a larger gas nozzle (2mm, Helium), we can investigate the dynamics of the plasma behind the critical surface
- Filaments seen parallel to laser direction extending up to 800 microns into gas target

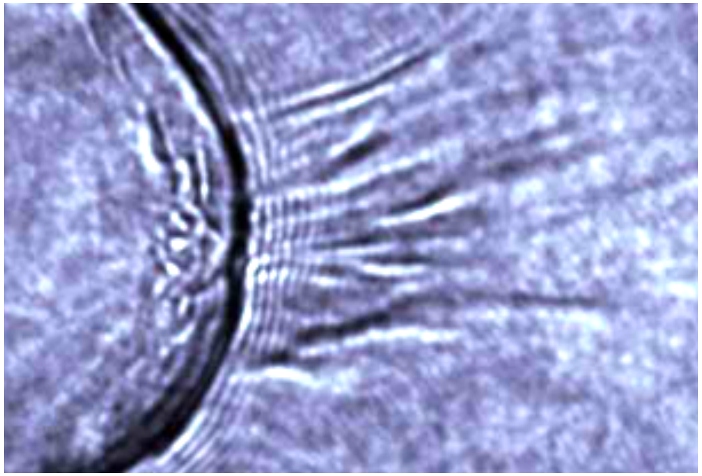


2D PIC reveals filamentation instability

Using the output from hydrodynamic simulations of blast wave:





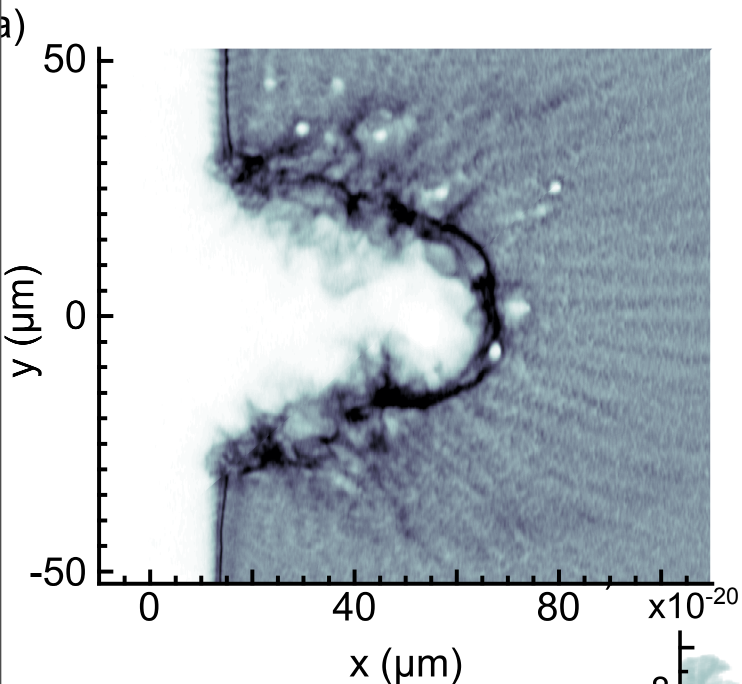


What does the future hold?

- Development of high power CO_2 lasers
  - BESTIA 100-TW CO_2 laser upgrade for ATF2^:
    - Completed: Solid state OPA front end
    - Completed: CPA proof-of-principle for CO_2 lasers*
    - Funded: New amplifier chain & femtosecond compression:
      - higher energy output (>35 J),
      - higher repetition rate (10 Hz)
      - <500 fs pulse length
  - Important to investigate energy scaling and stability of acceleration from gas jet target

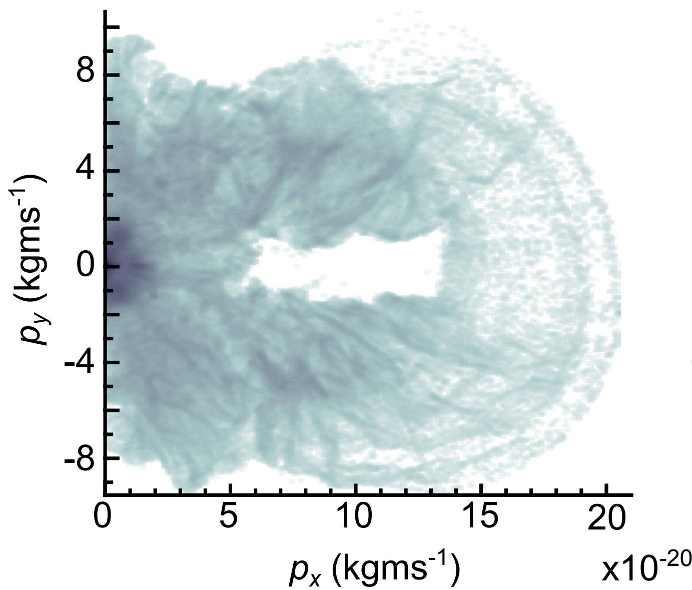
^Pogorelsky & Ben-Zvi, PPCF ***56*** *(2013)*
Polyanskiy et al., Optica* ***2* *(2015)*

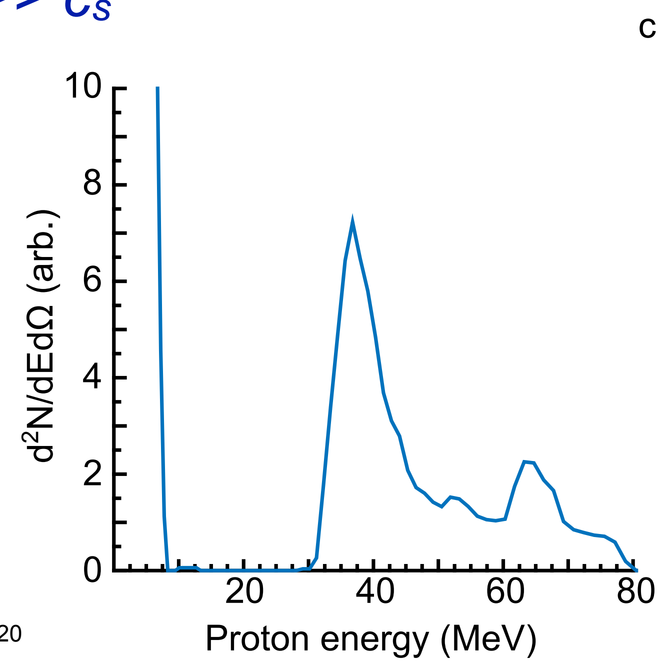
What does the future hold?



Modelling using predicted new capabilities:

- Ions accelerated > 50 MeV, depending on focusing
- Require targets ~ 10 n_c, easily achievable with gas jets
- Acceleration is entirely from radiation pressure, as $v_b >> c_s$





Conclusion

- Developed technique of all-optical shaping of an overcritical gas target using secondary pulse
- Demonstration of proton and helium beams from shock acceleration
- High current electron beam filamentation in plasma
- New BESTIA laser at ATF2 will provide 100-TW at $\lambda_L = 10$ μm for ion acceleration studies