Laser driven shockwave acceleration of ions with optically shaped gas jets

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BNL ion acceleration experiments

John Adams Institute for Accelerator Science
Imperial College London

N.P. Dover, G. Hicks, Z. Najmudin

BROOKHAVEN NATIONAL LABORATORY
Accelerator Test Facility

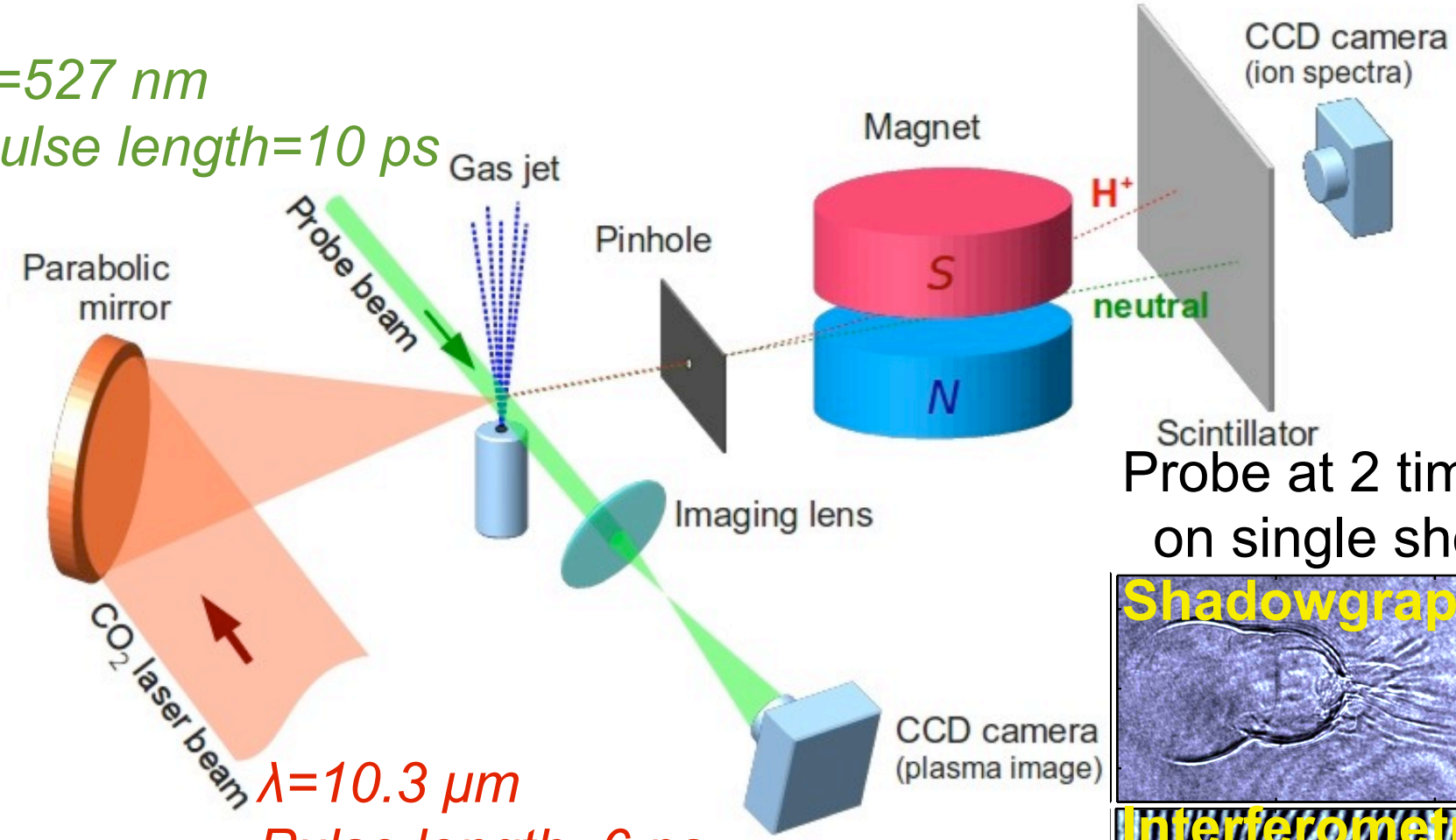
I.V. Pogorelsky, O. Tresca, M.N. Polyanskiy

Stony Brook University

N. Cook, C. Maharjan, P. Shkolnikov

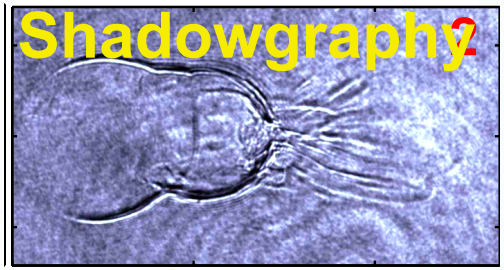
Experimental set-up

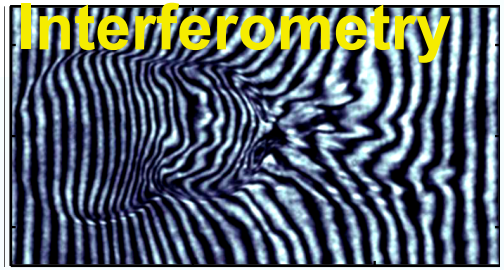
λ=527 nm
Pulse length=10 ps



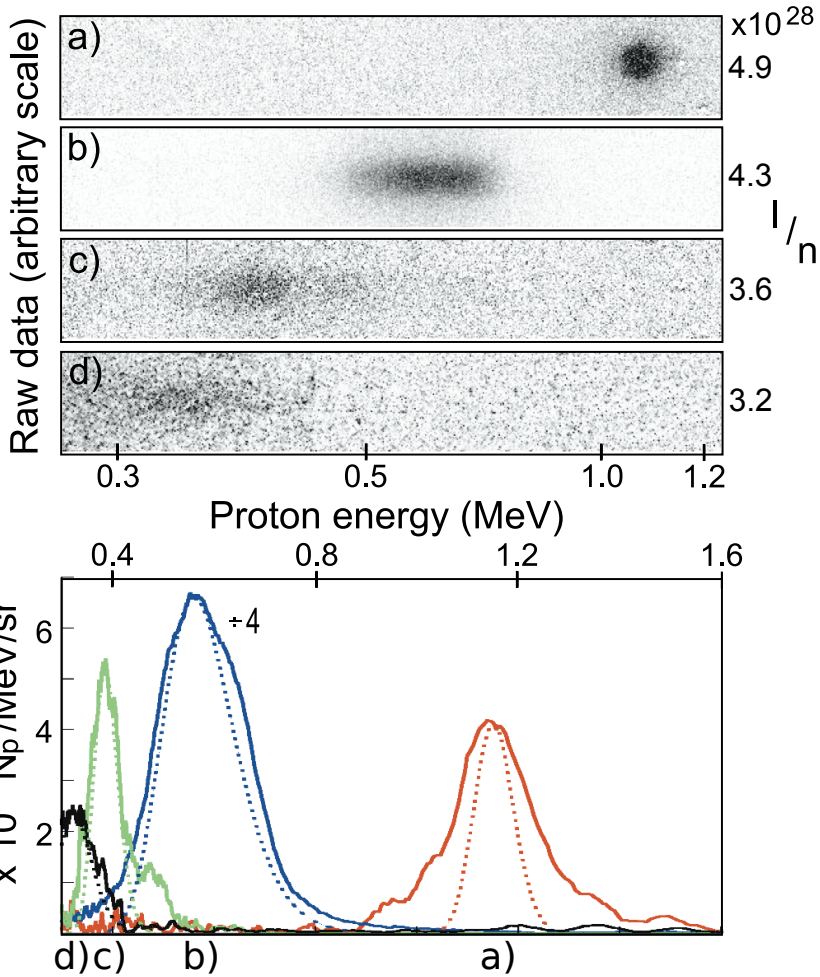
λ=10.3 μm
Pulse length=6 ps
Spot size = 70 μm
Intensity ~ 10^{16} W/cm^2

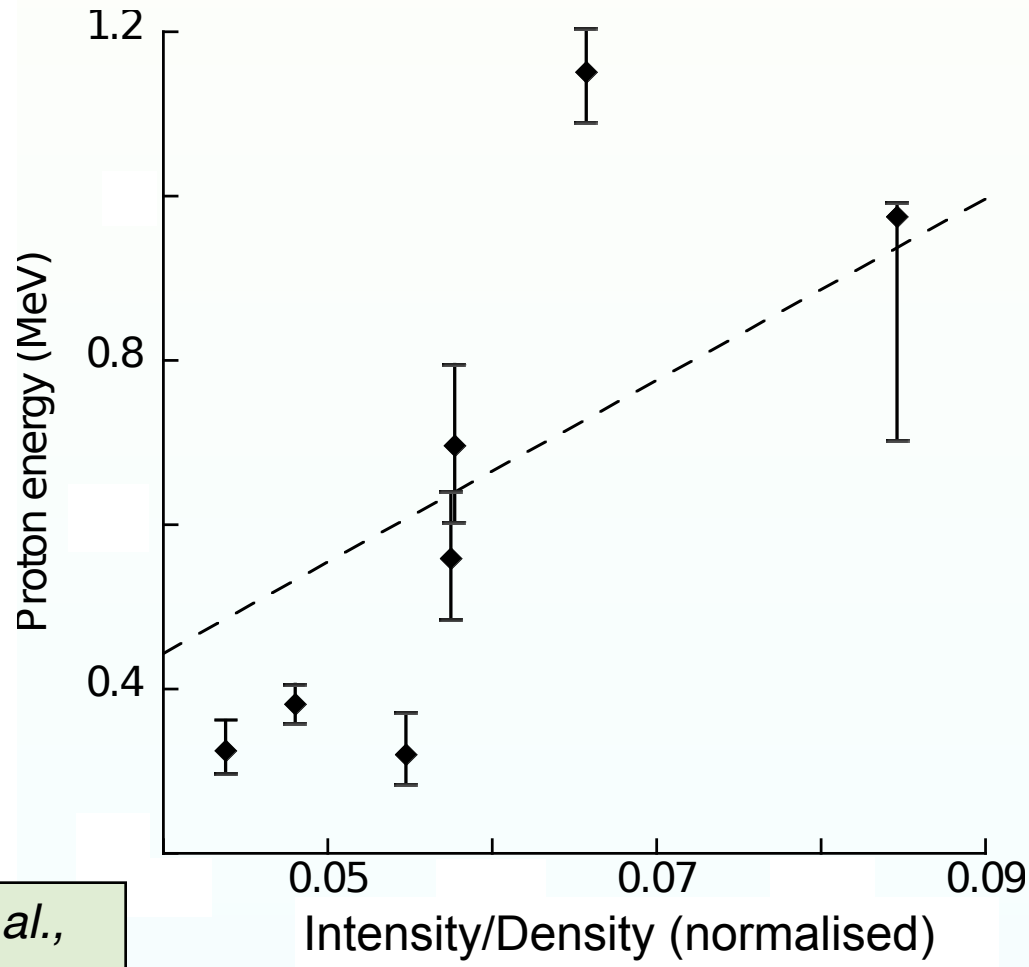
Probe at 2 times on single shot





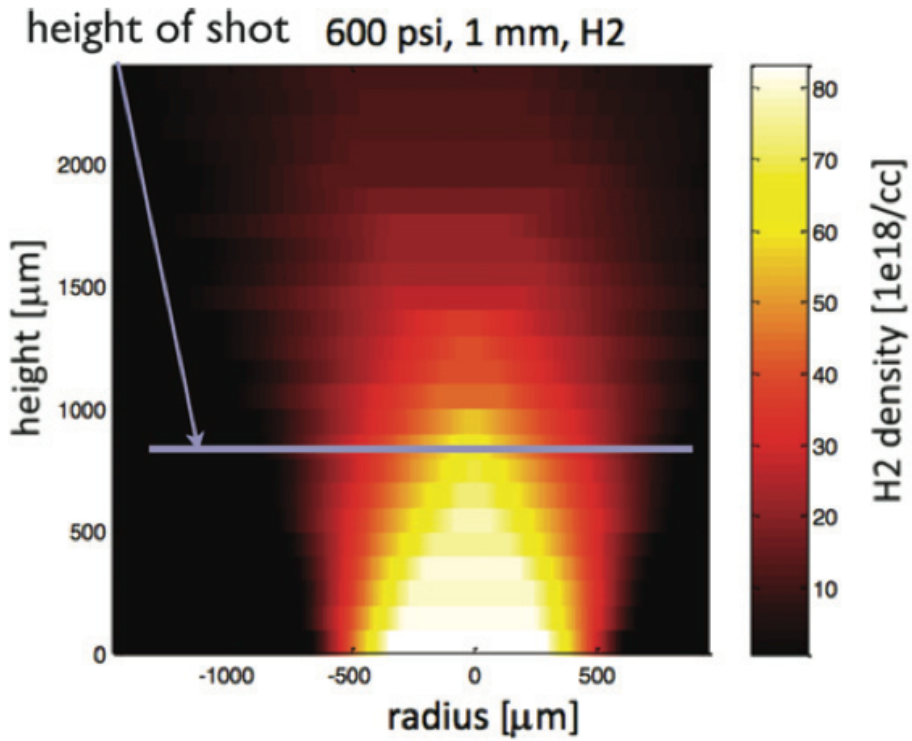
Generated monoenergetic proton beams

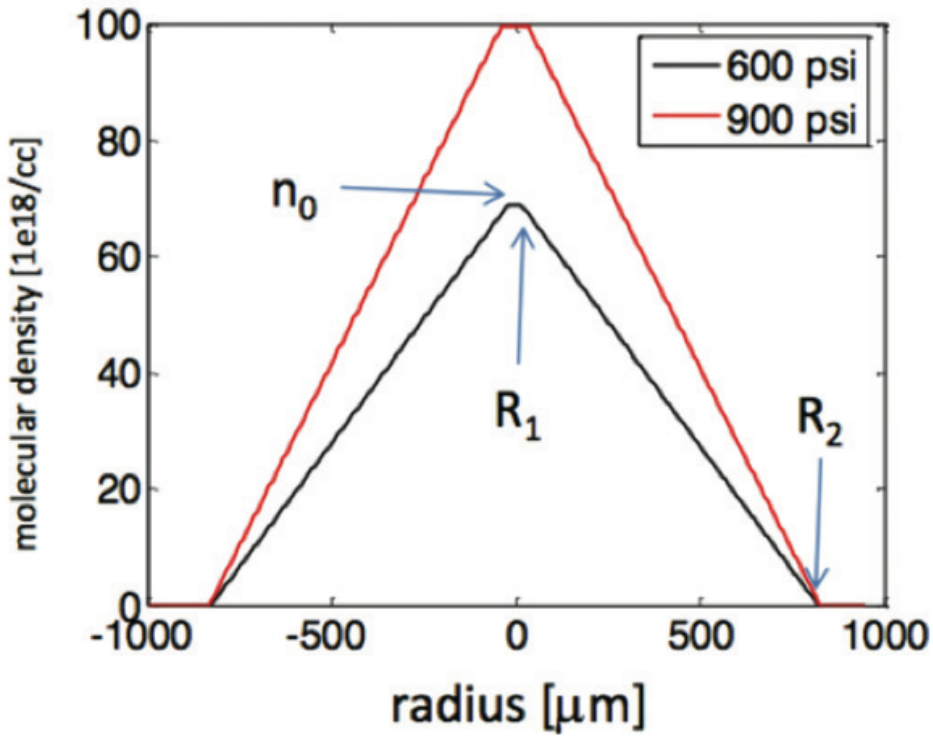




*See: Palmer, Dover, Pogorelsky et al., PRL, **106** (2011)*

Typical Gas profile

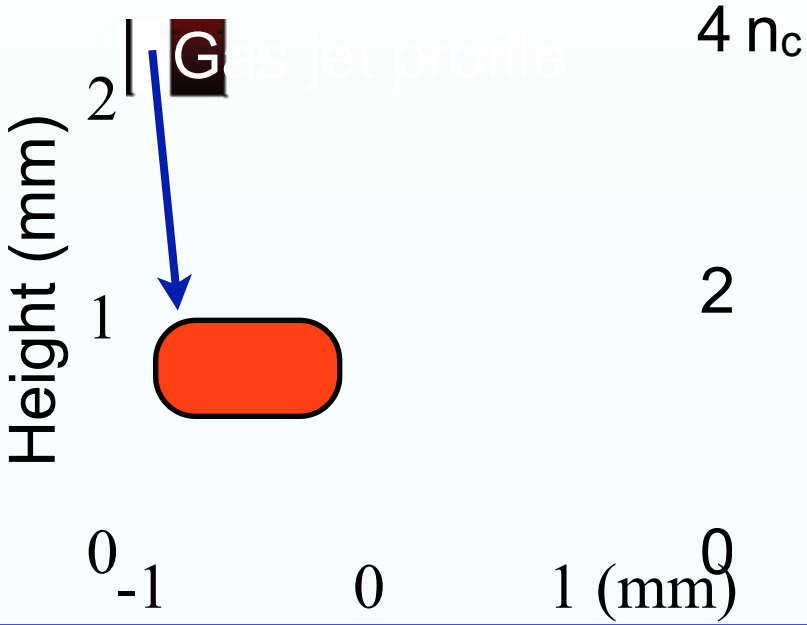




New technique: blast wave shaping

- *Single intense pulse* to drive acceleration controllably
- Prepulse 25 ns before main pulse to optically tailor density
- Helium gas to generate helium beams with shock acceleration

Prepulse deposits energy, gas expands and forms blast wave



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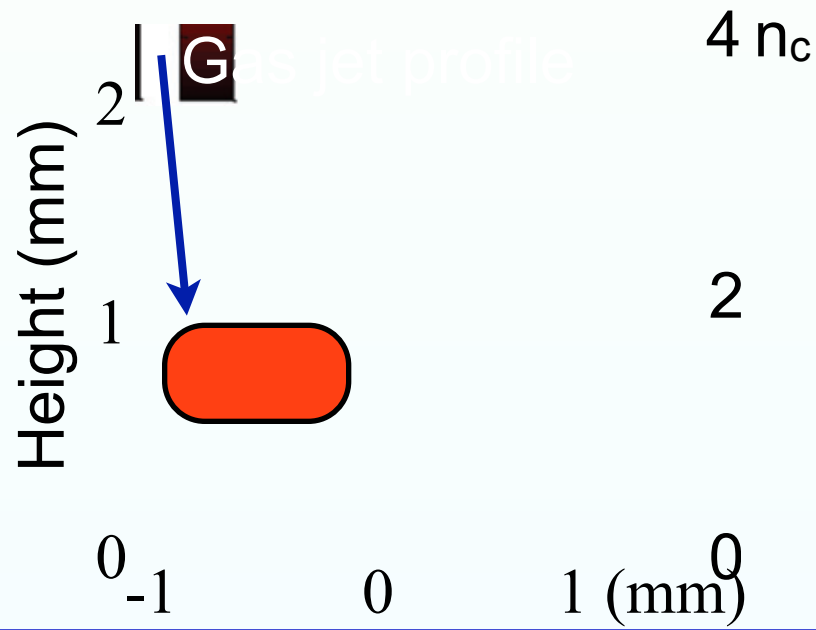
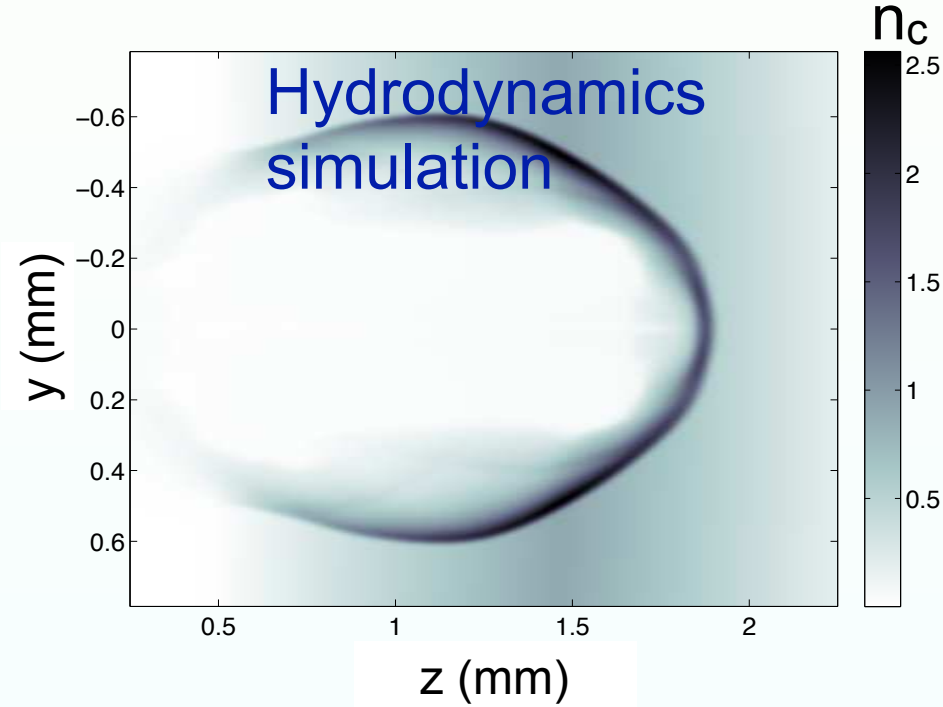
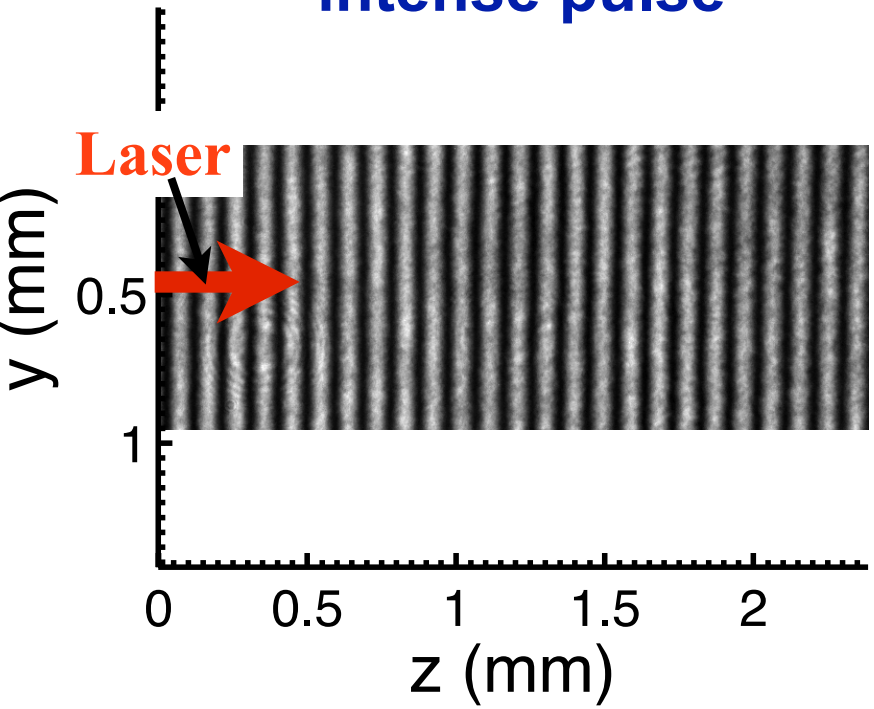




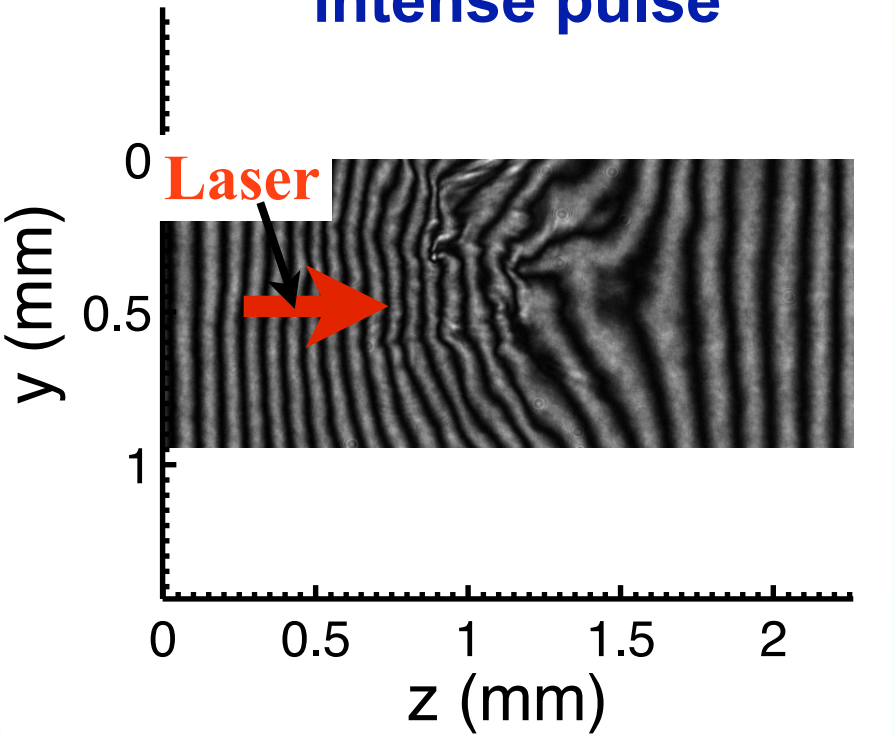
Main pulse interacts with steepened profile

Varying prepulse changes initial conditions

400 ps <u>before</u> intense pulse



100 ps <u>after</u> intense pulse



Varying prepulse changes initial conditions

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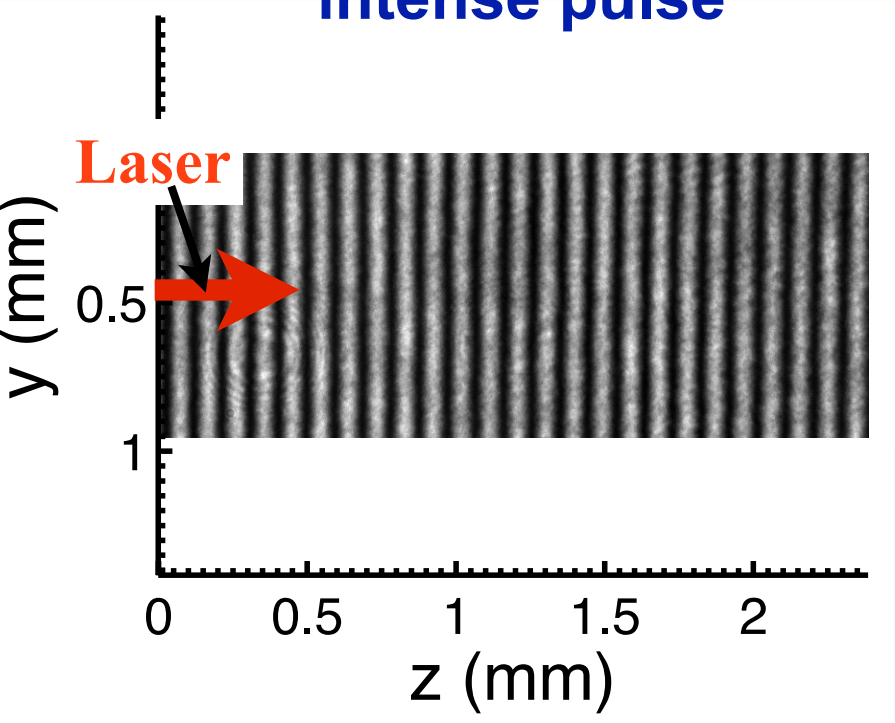

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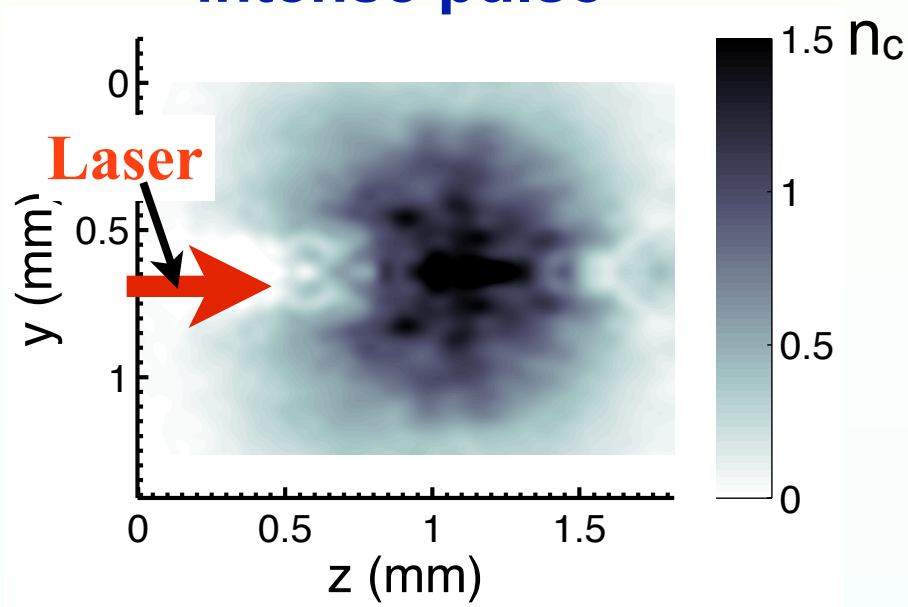
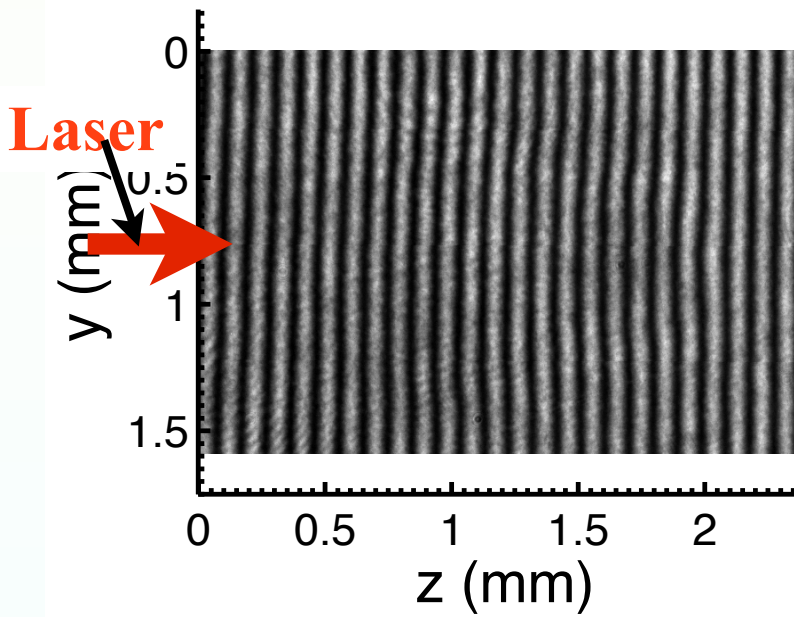


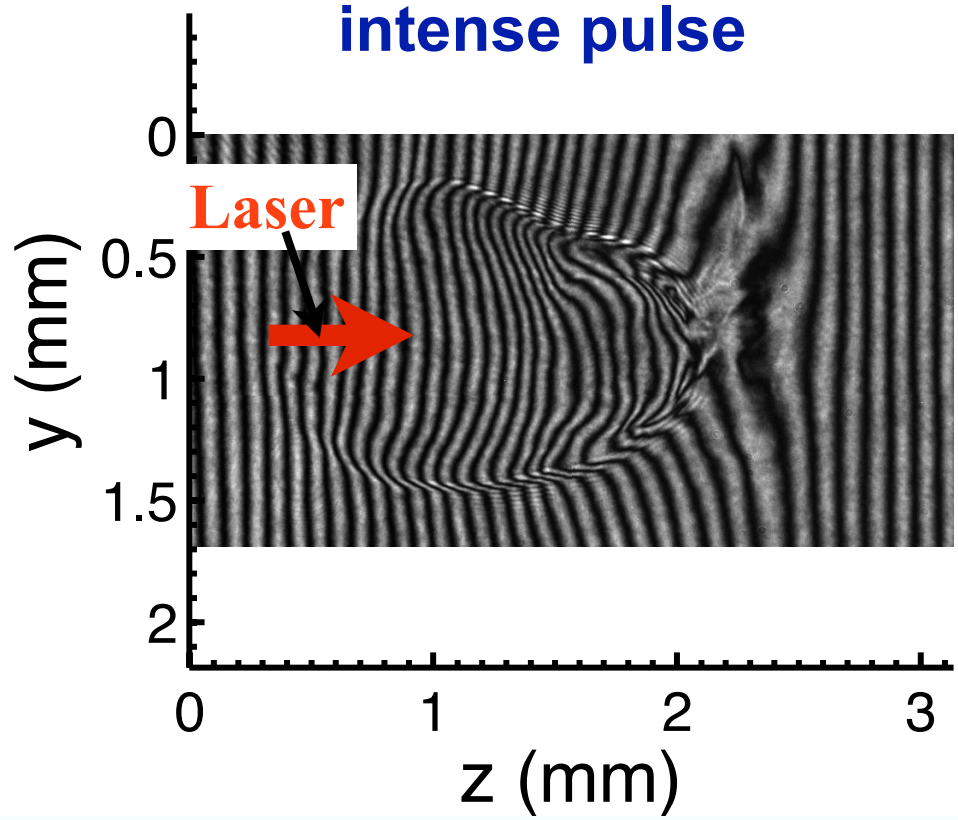
- No prepulse: intense pulse expends energy channeling up density ramp
  - **<u>No ion acceleration!</u>**

Varying prepulse changes initial conditions

400 ps before intense pulse

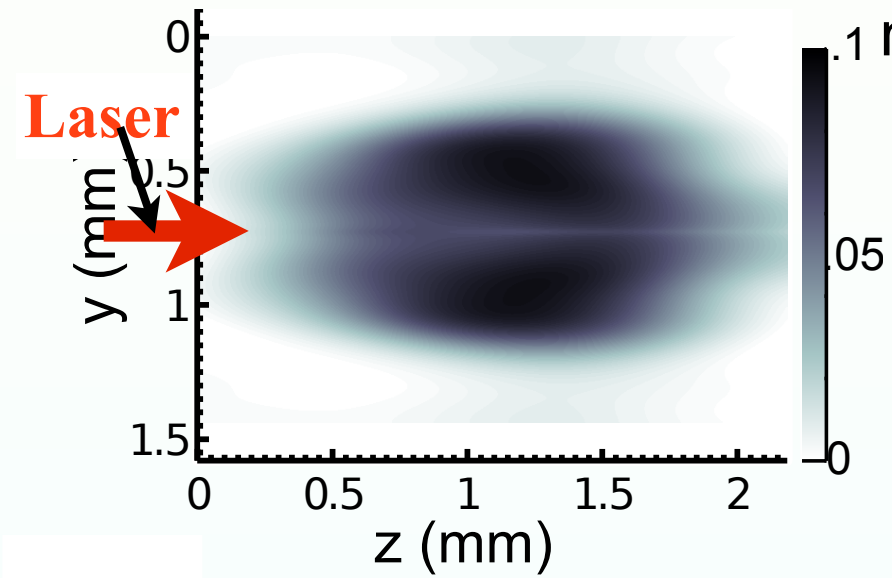


100 ps after intense pulse

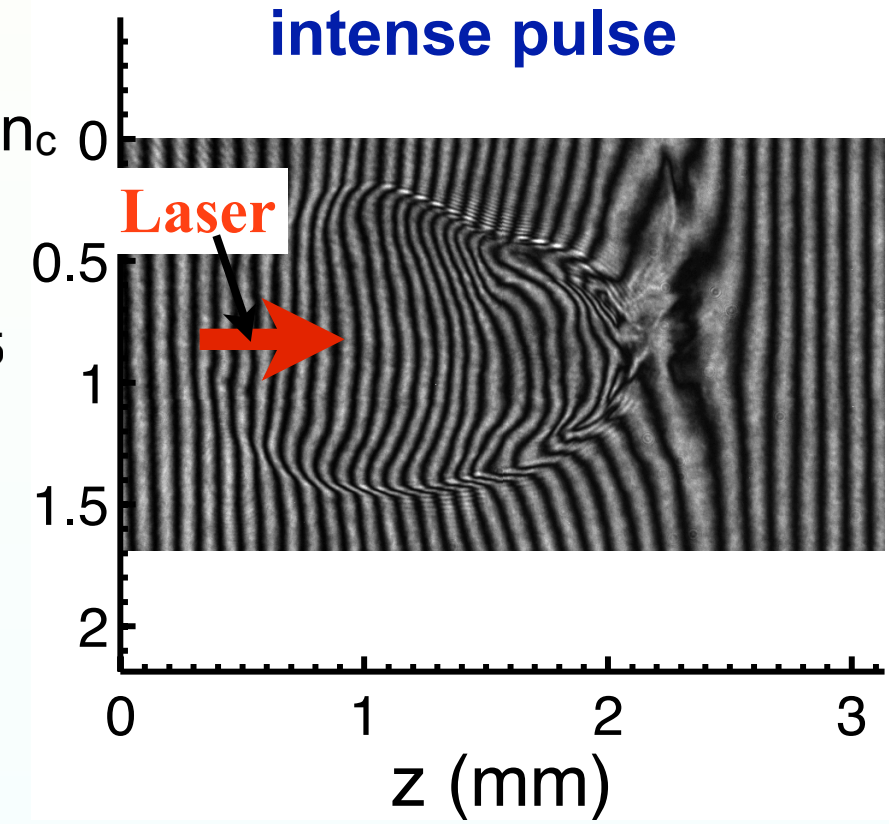


Varying prepulse changes initial conditions

400 ps before intense pulse

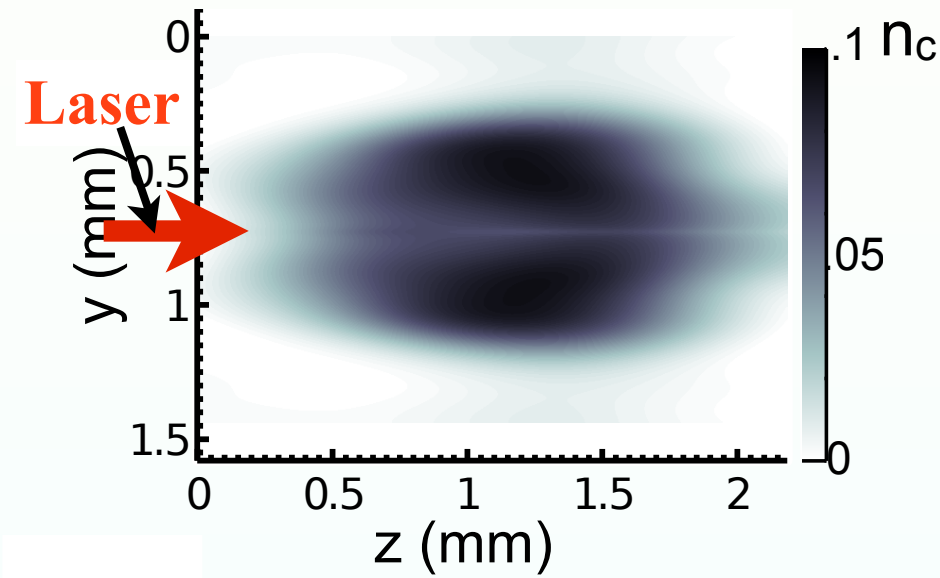


100 ps after intense pulse

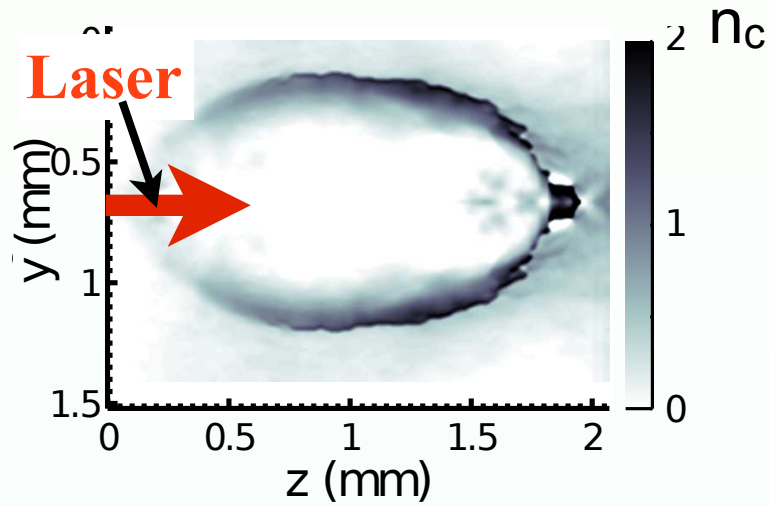


Varying prepulse changes initial conditions

400 ps <u>before</u> intense pulse



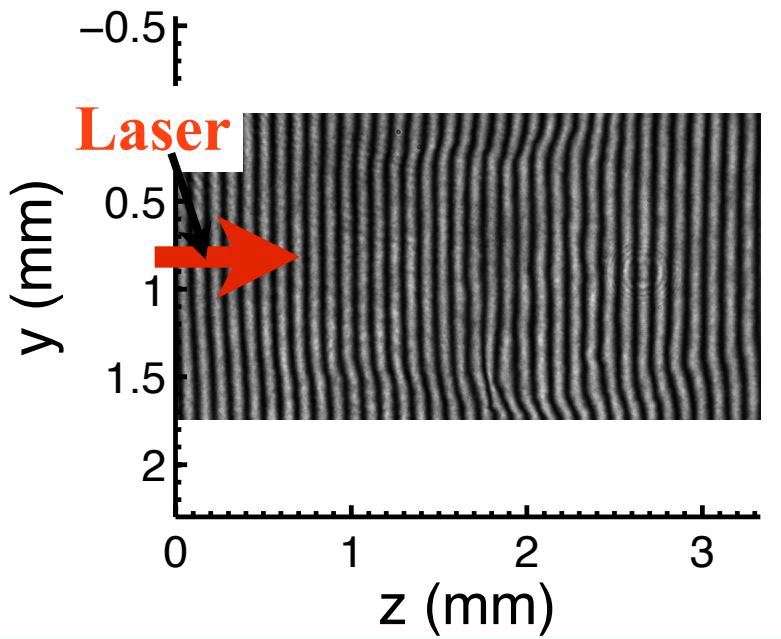
100 ps <u>after</u> intense pulse



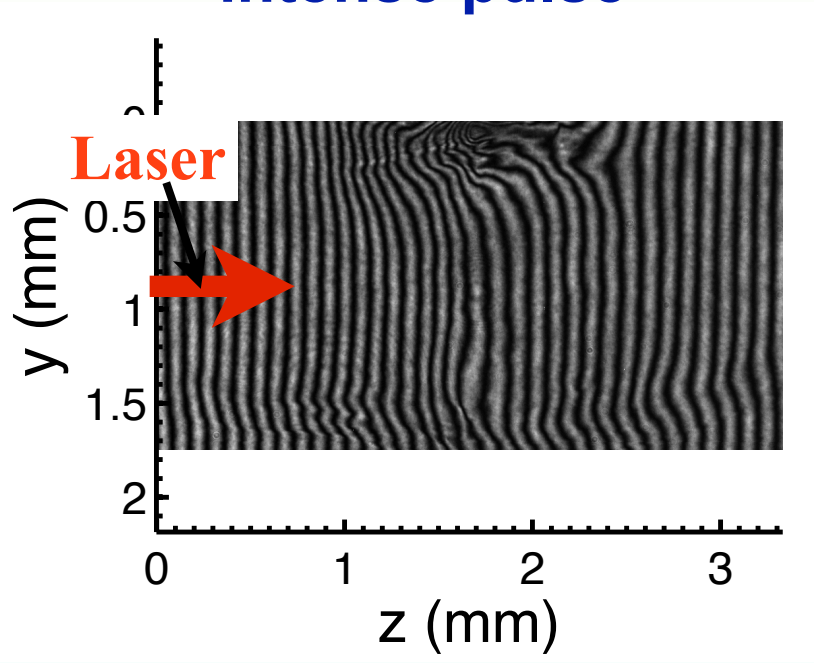
- "100 mJ" prepulse: significant preionisation prior to the interaction, indicative of optical tailoring of gas jet
  - **<u>First observation of energetic helium ions from shockwave acceleration in overdense gas-jets</u>**

Varying prepulse changes initial conditions

400 ps <u>before</u> intense pulse



100 ps <u>after</u> intense pulse



Varying prepulse changes initial conditions

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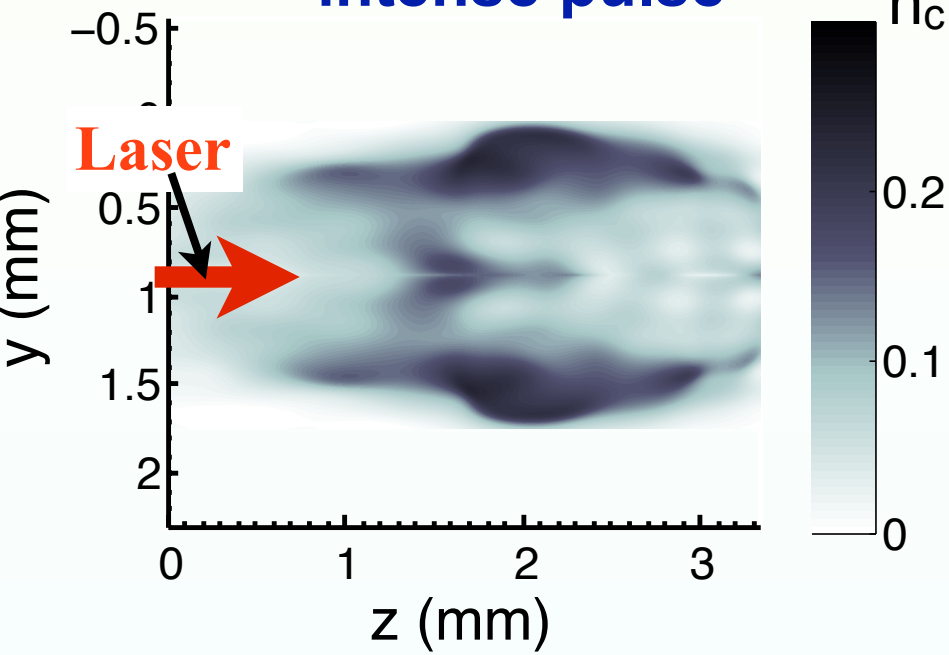
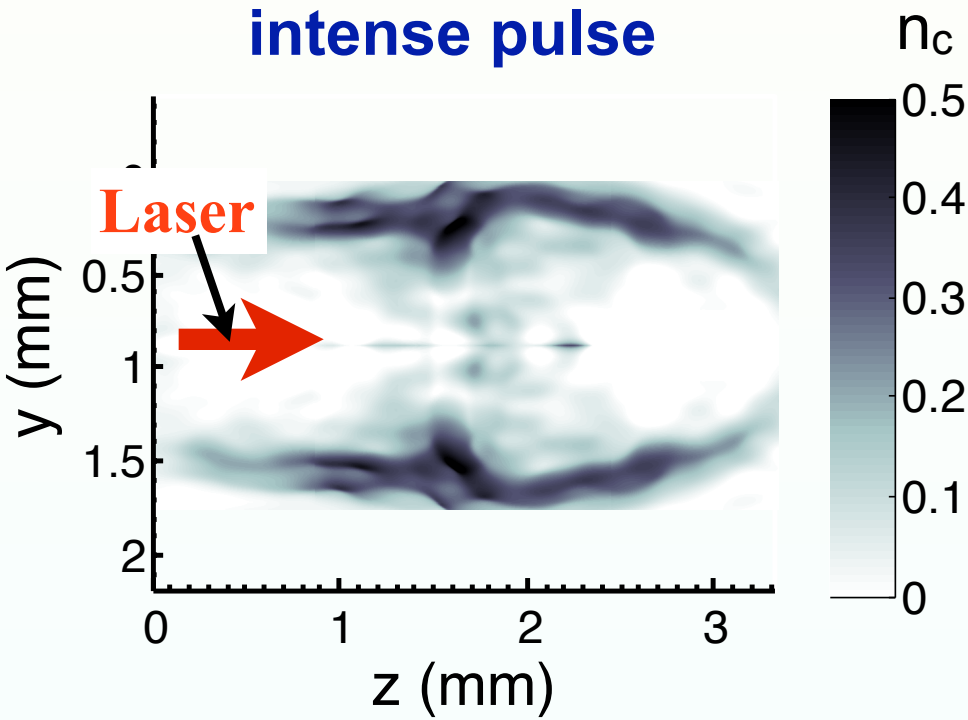
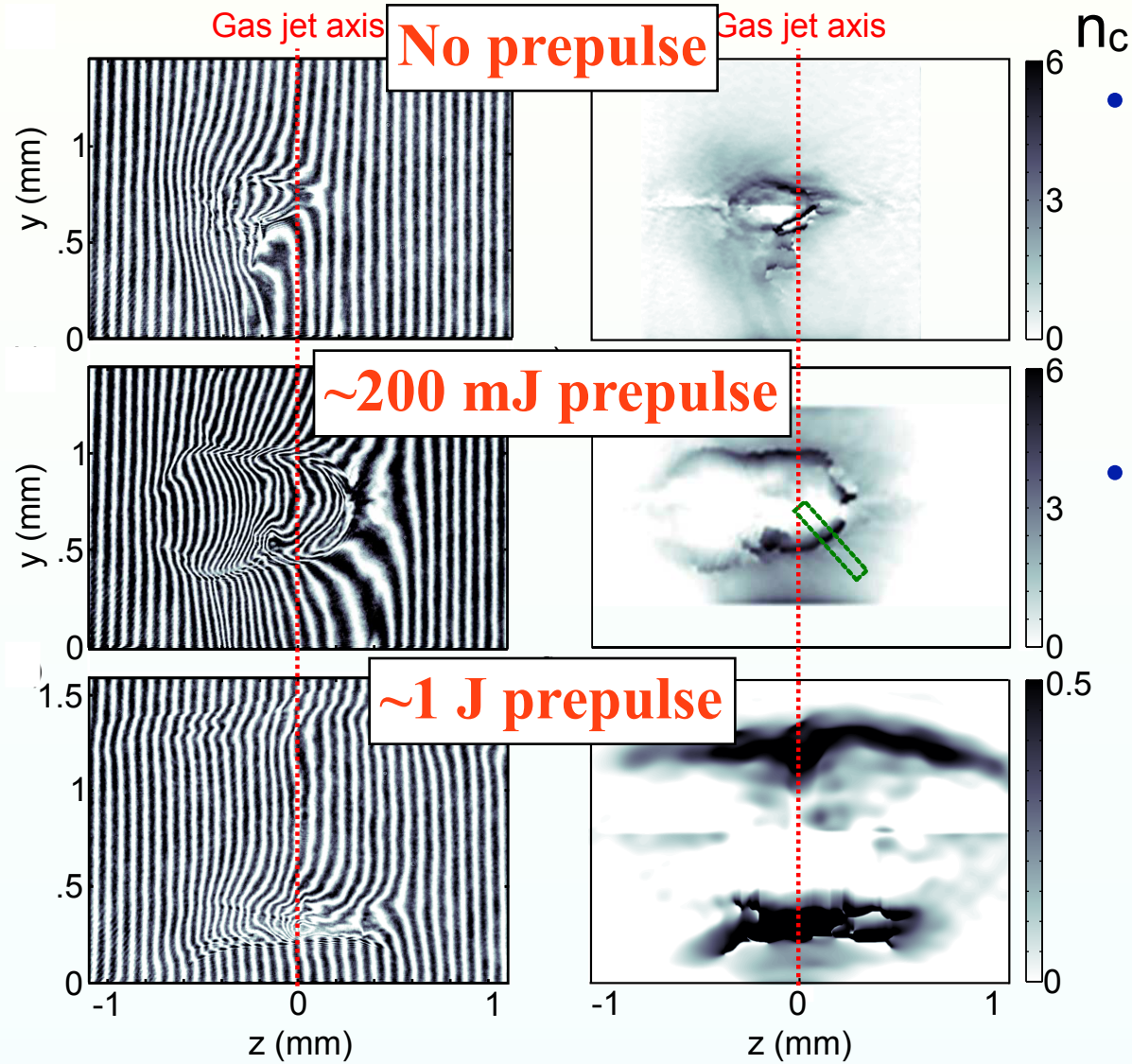


100 ps <u>after</u> intense pulse



- "200+ mJ" prepulse: prepulse heats filament which expands too much, causing intense pulse to go straight through gas jet
  - **<u>No ion beams generated</u>**

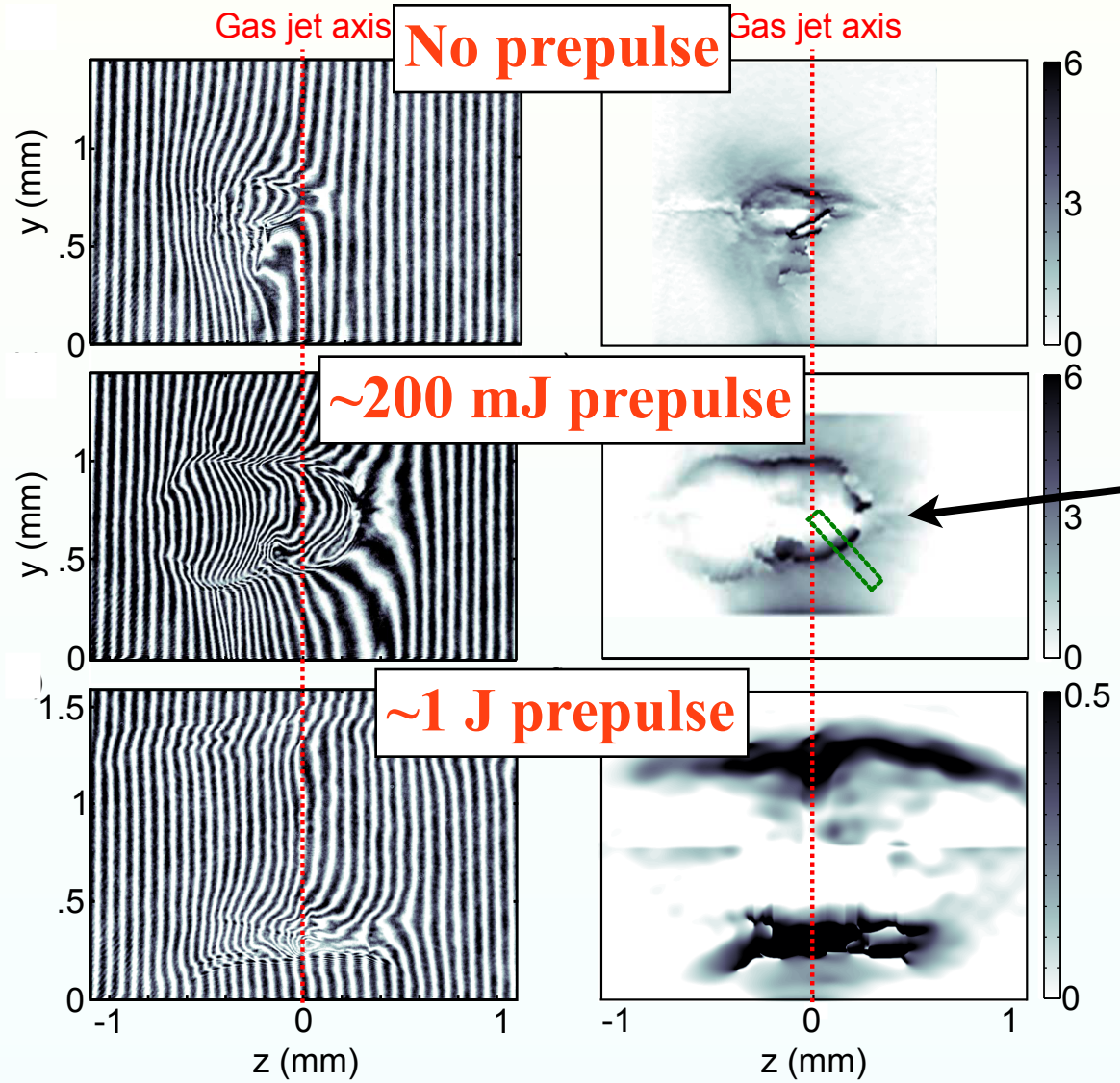
Varying prepulse changes ion beam properties

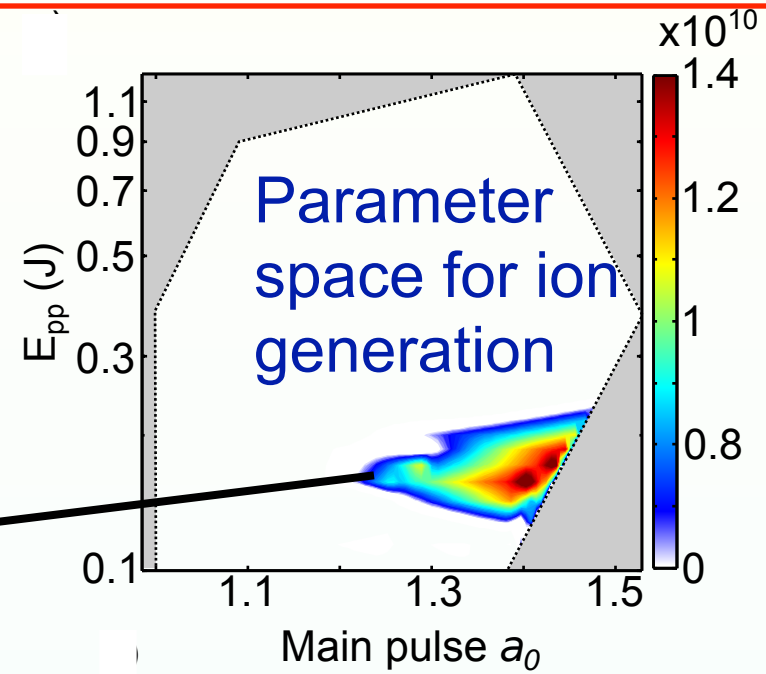


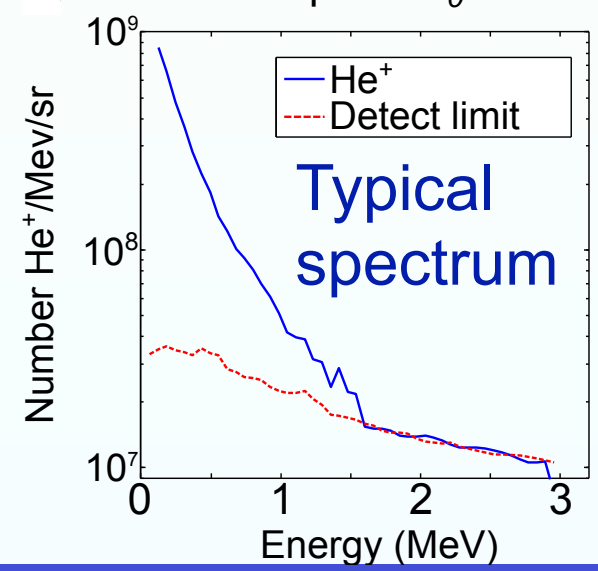
- Using ~100 mJ prepulse generates ~10λ density ramp for main pulse to interact with
- Sharp density ramp allows efficient *localised* heating & shock generation

See: Tresca, Dover, Cook et al., Submitted 2014

Varying prepulse changes ion beam properties

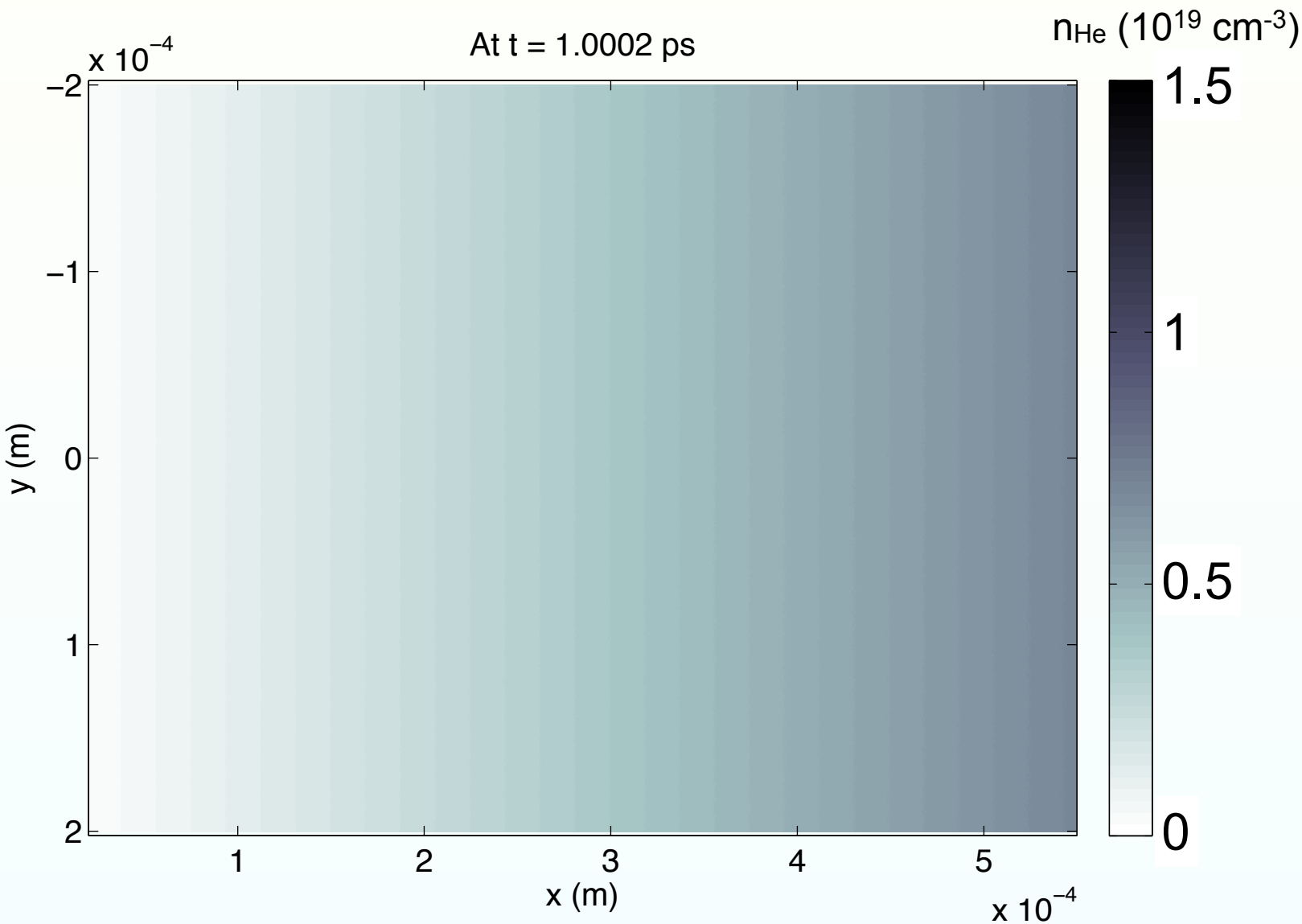






See: Tresca, Dover, Cook et al., Submitted 2014

2D PIC, no prepulse



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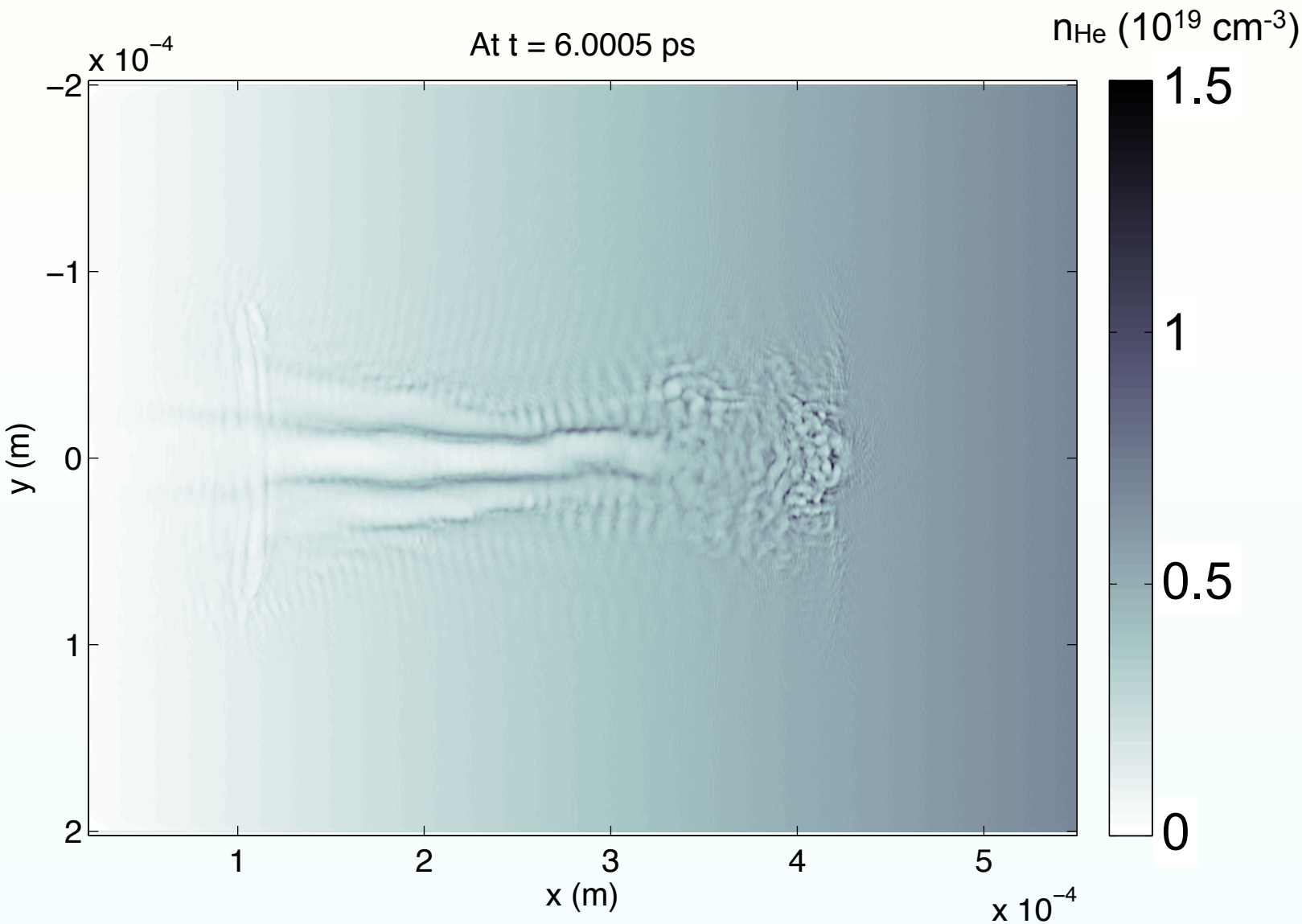

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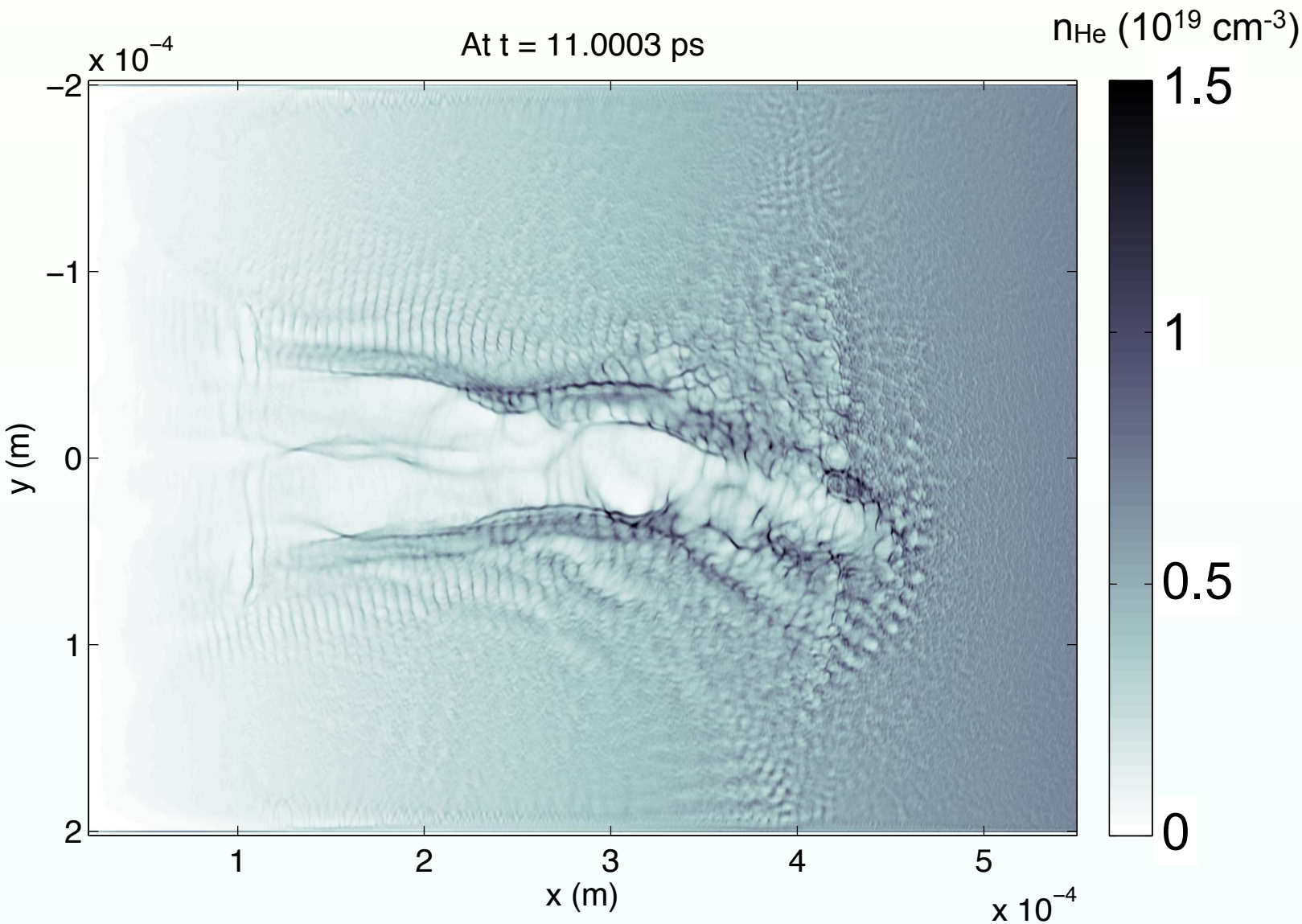

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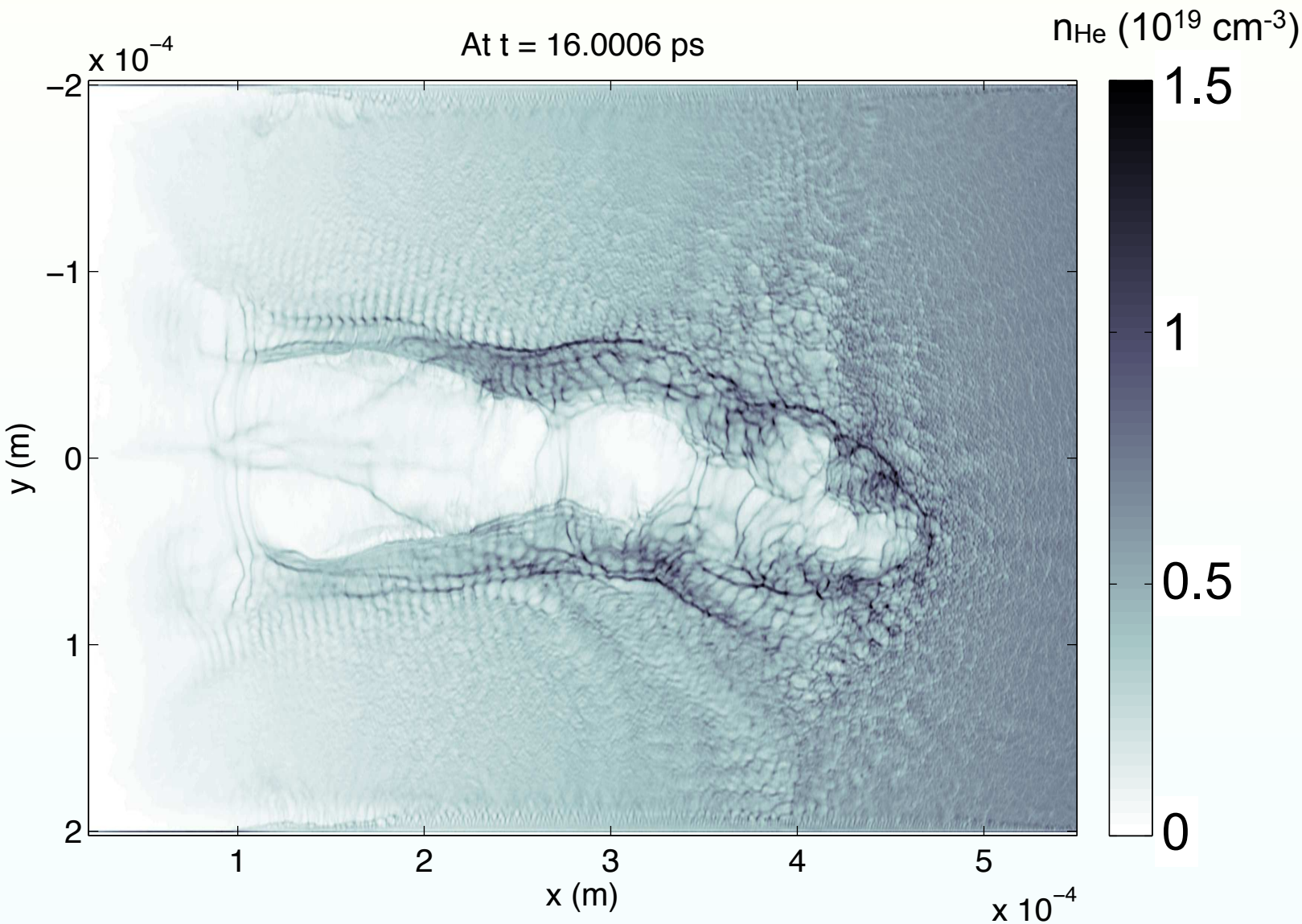

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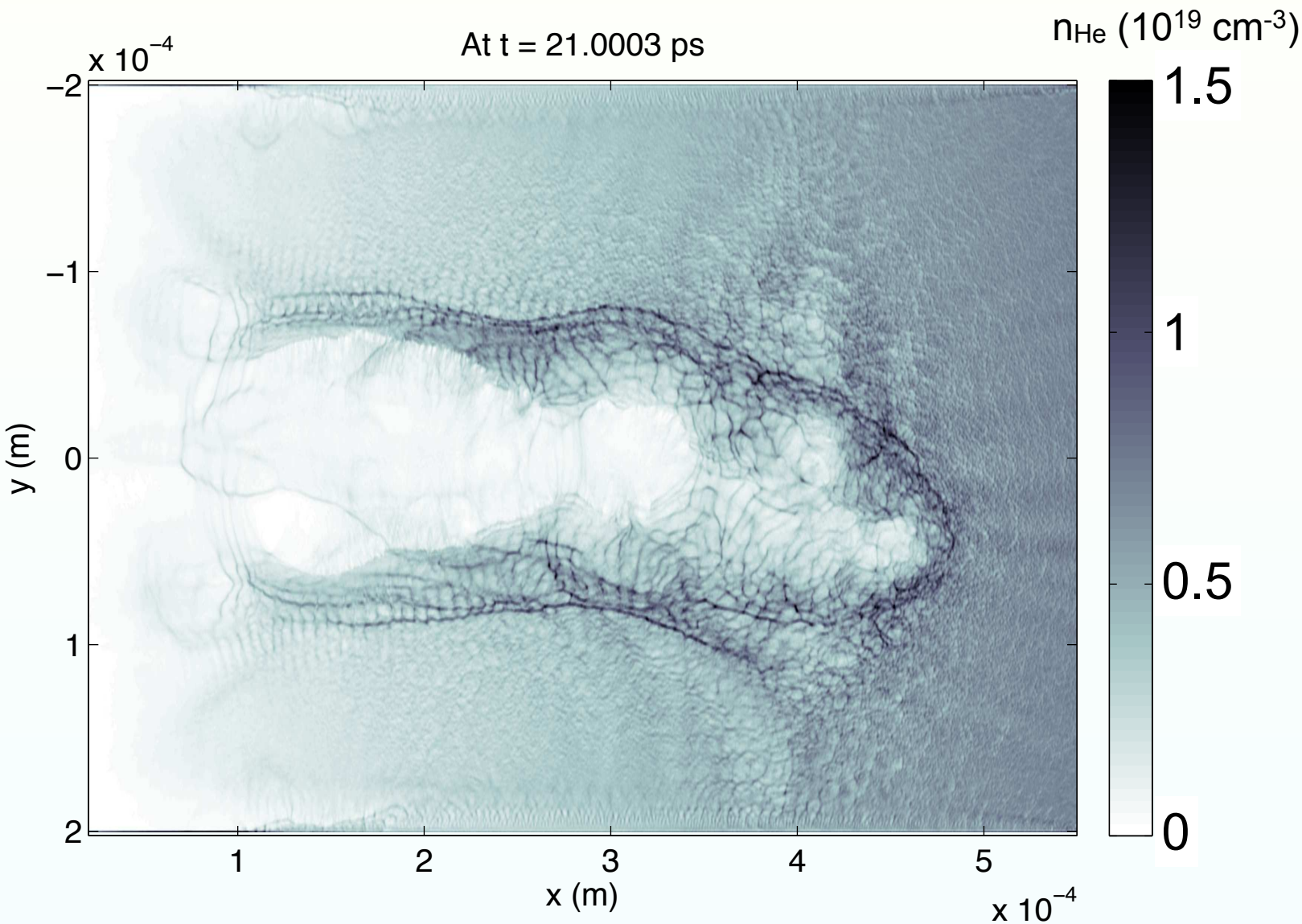

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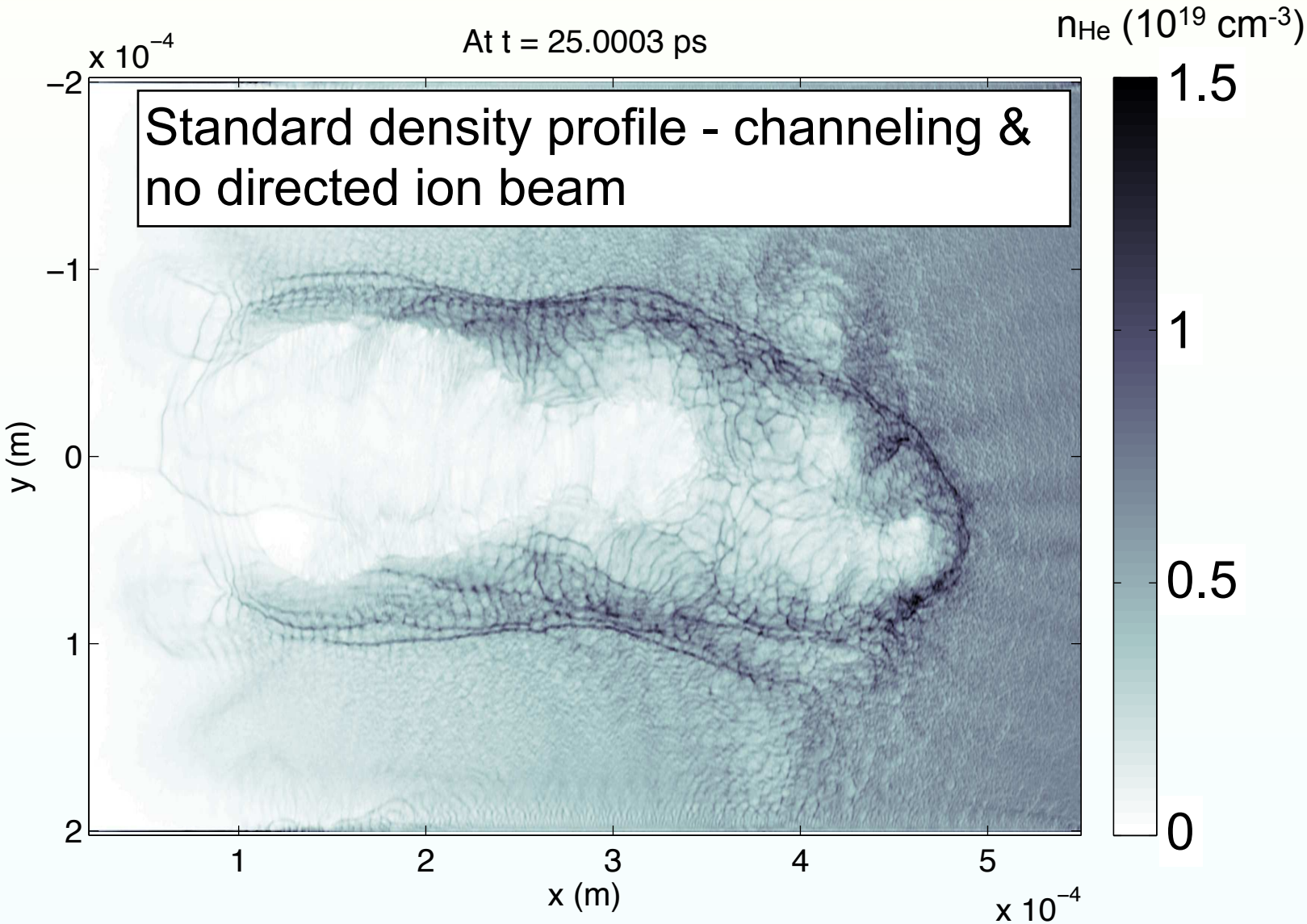

2D PIC, no prepulse

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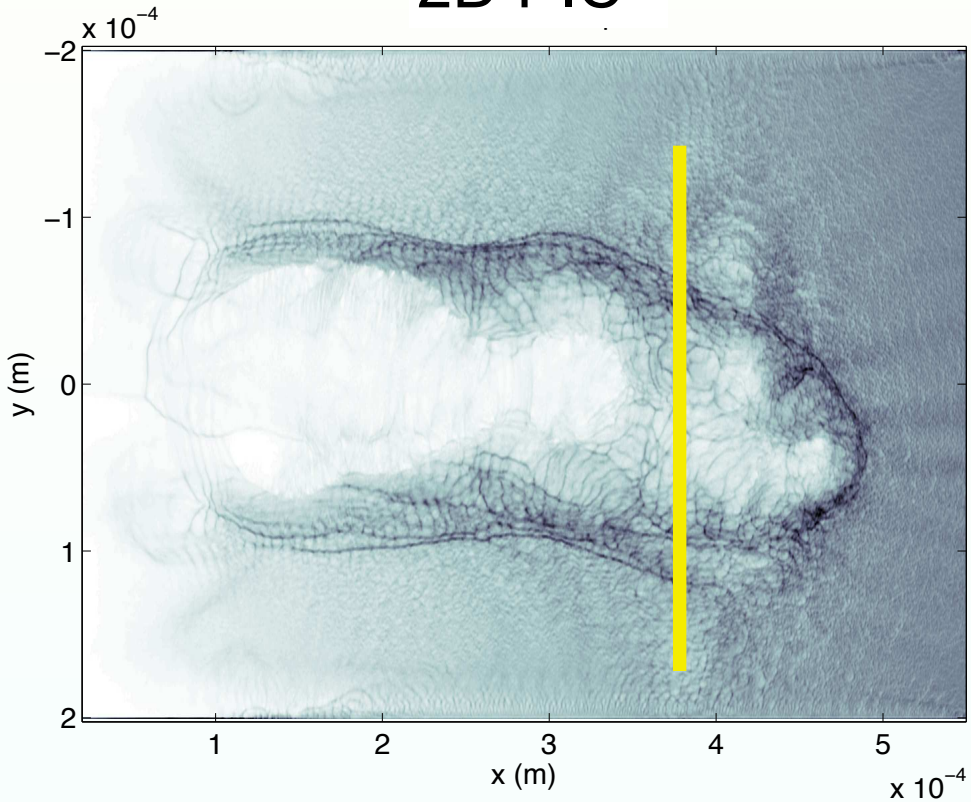
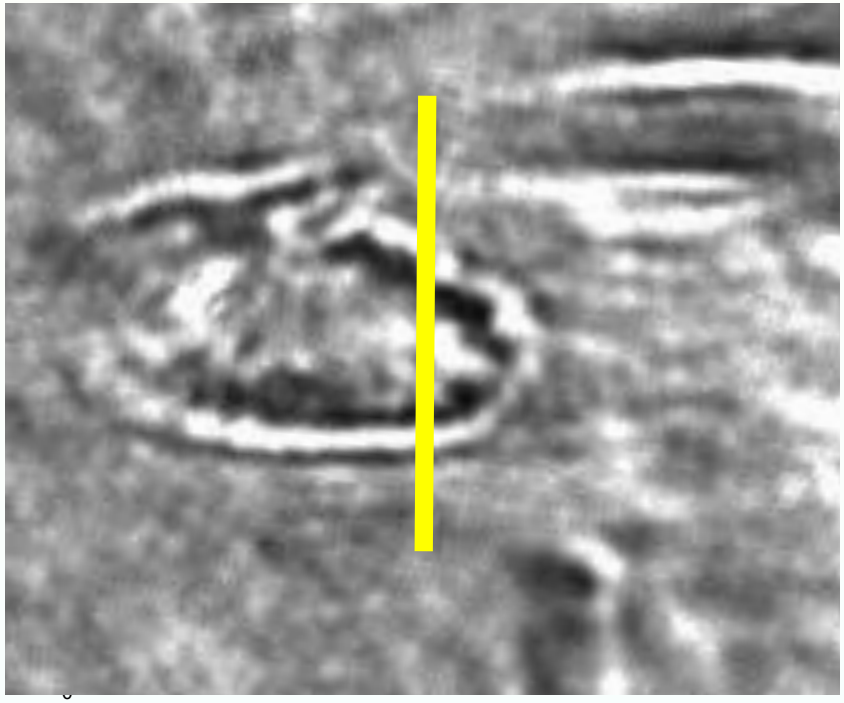
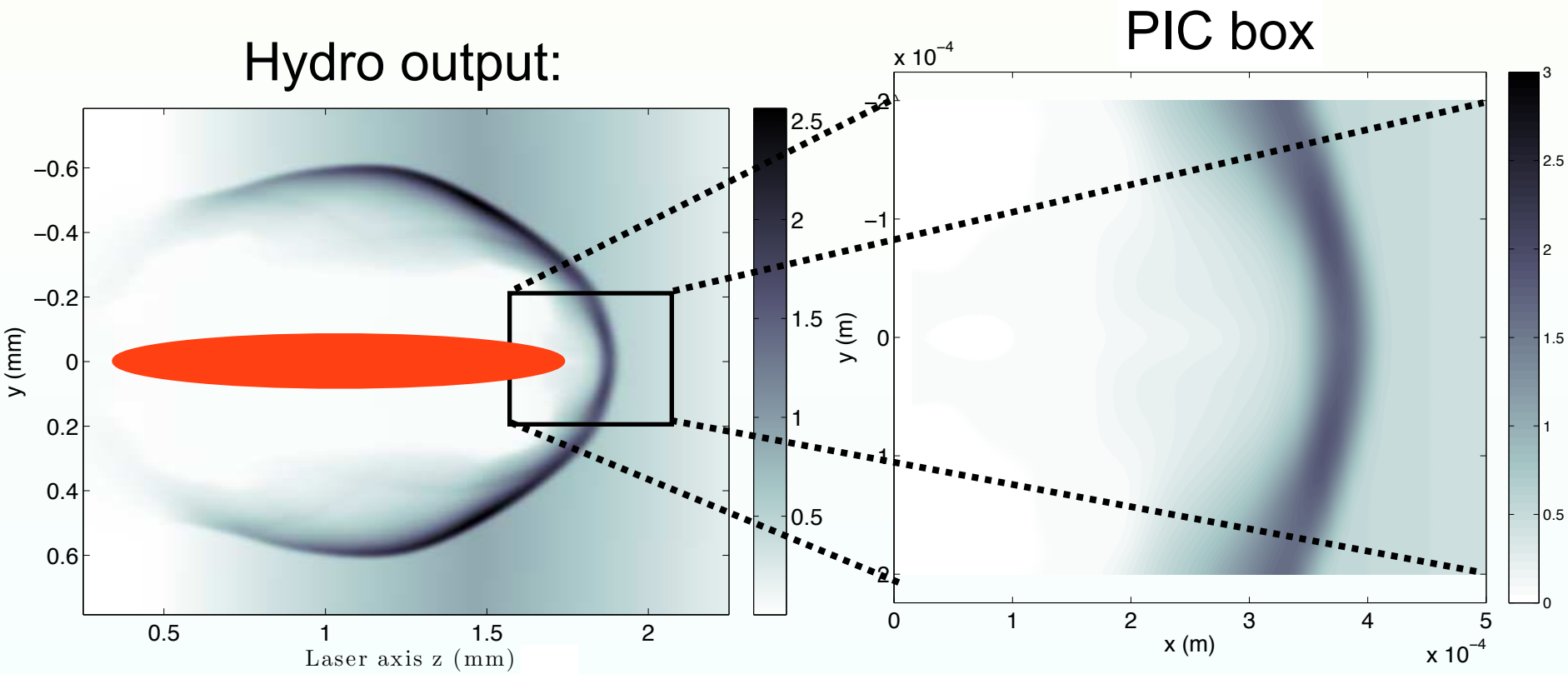


Experiment



2D PIC with prepulse



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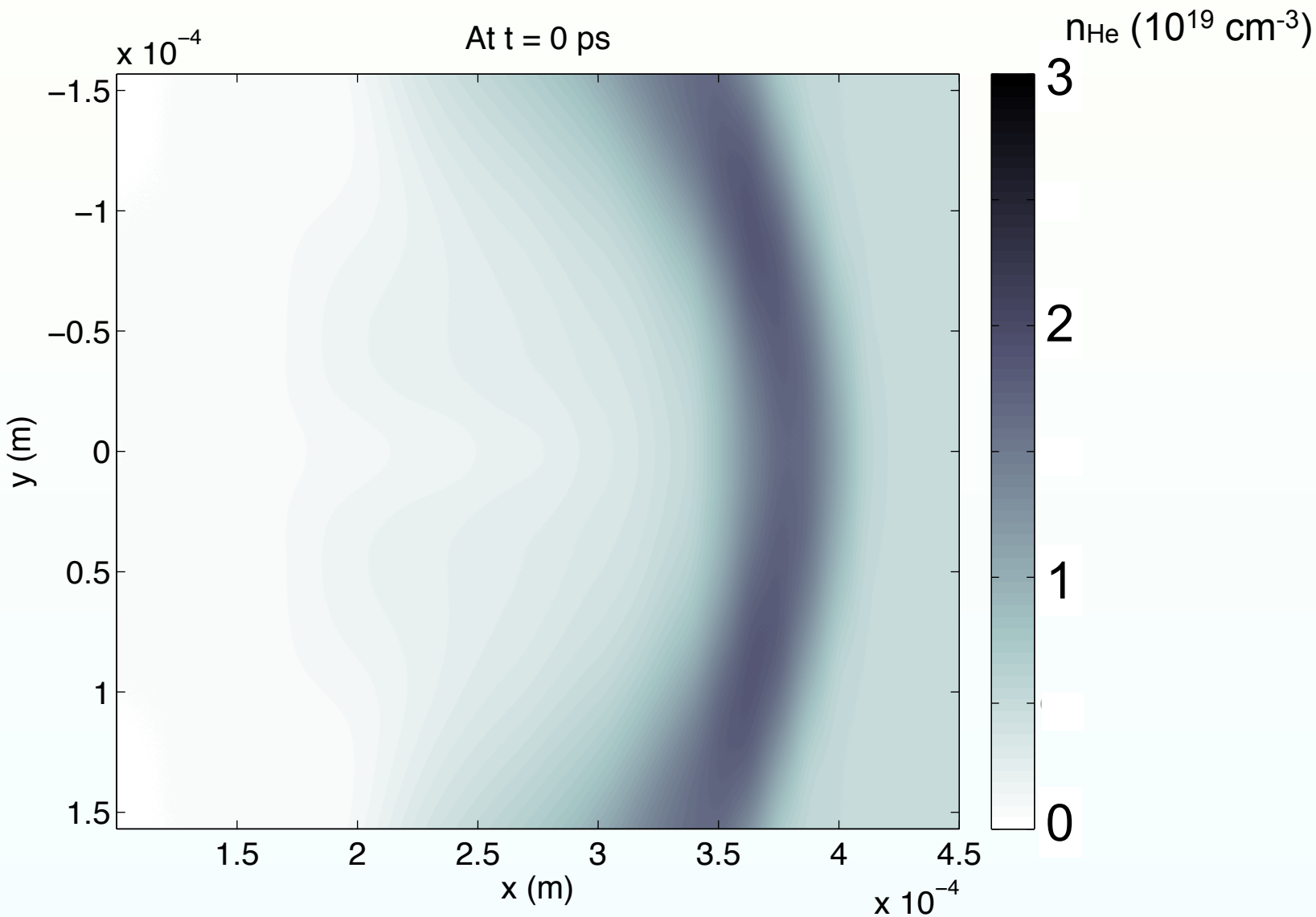
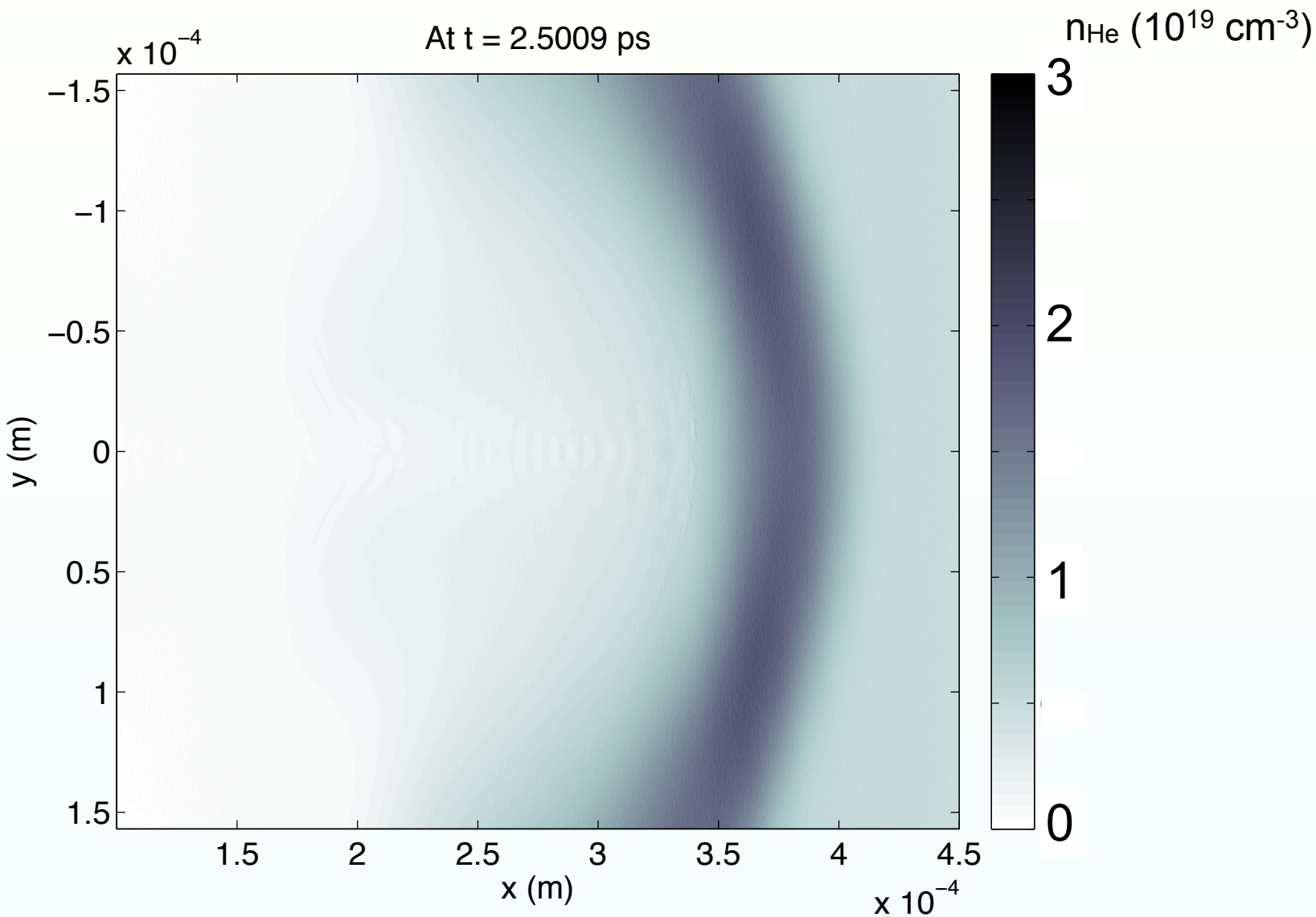


2D PIC with prepulse



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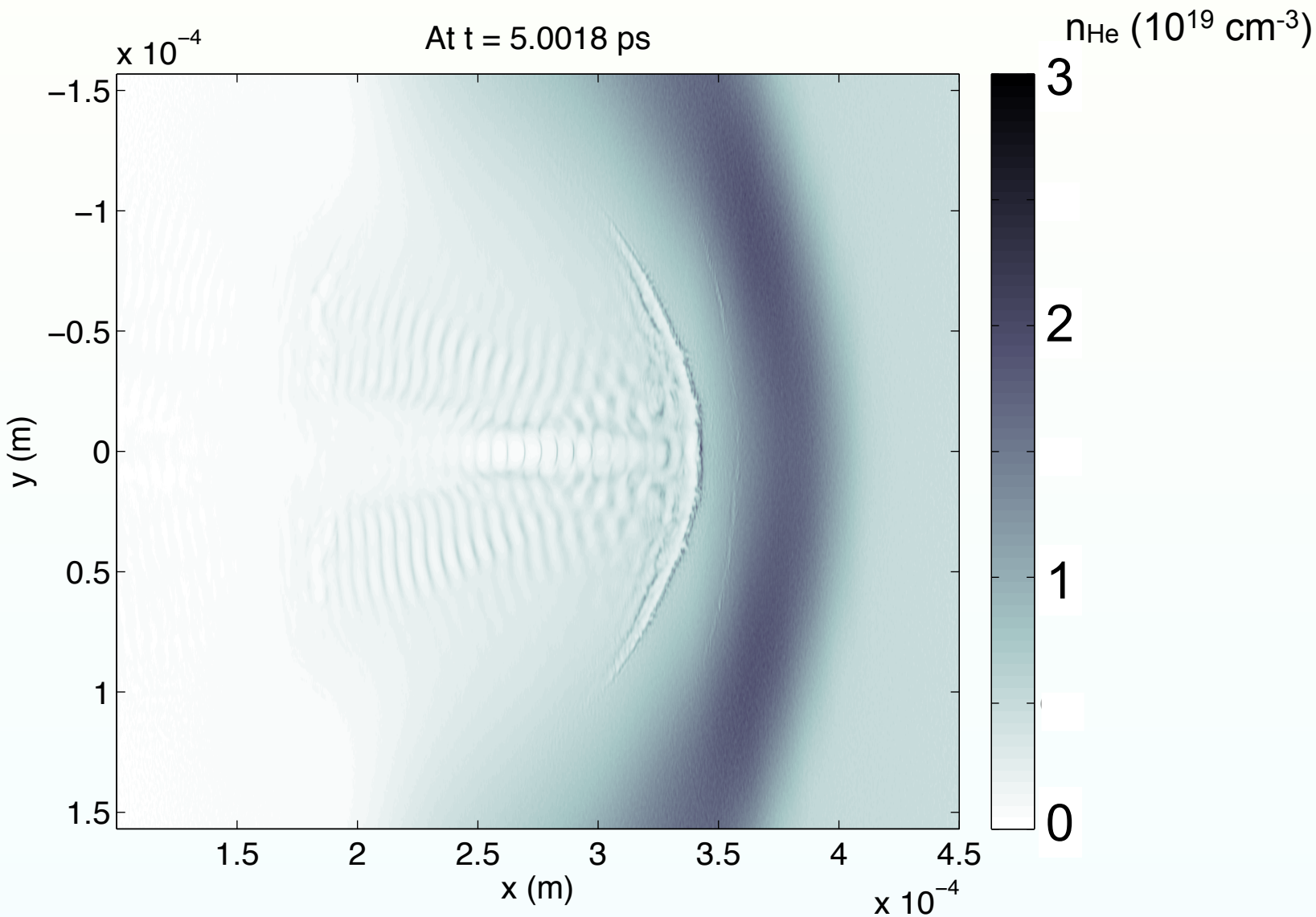
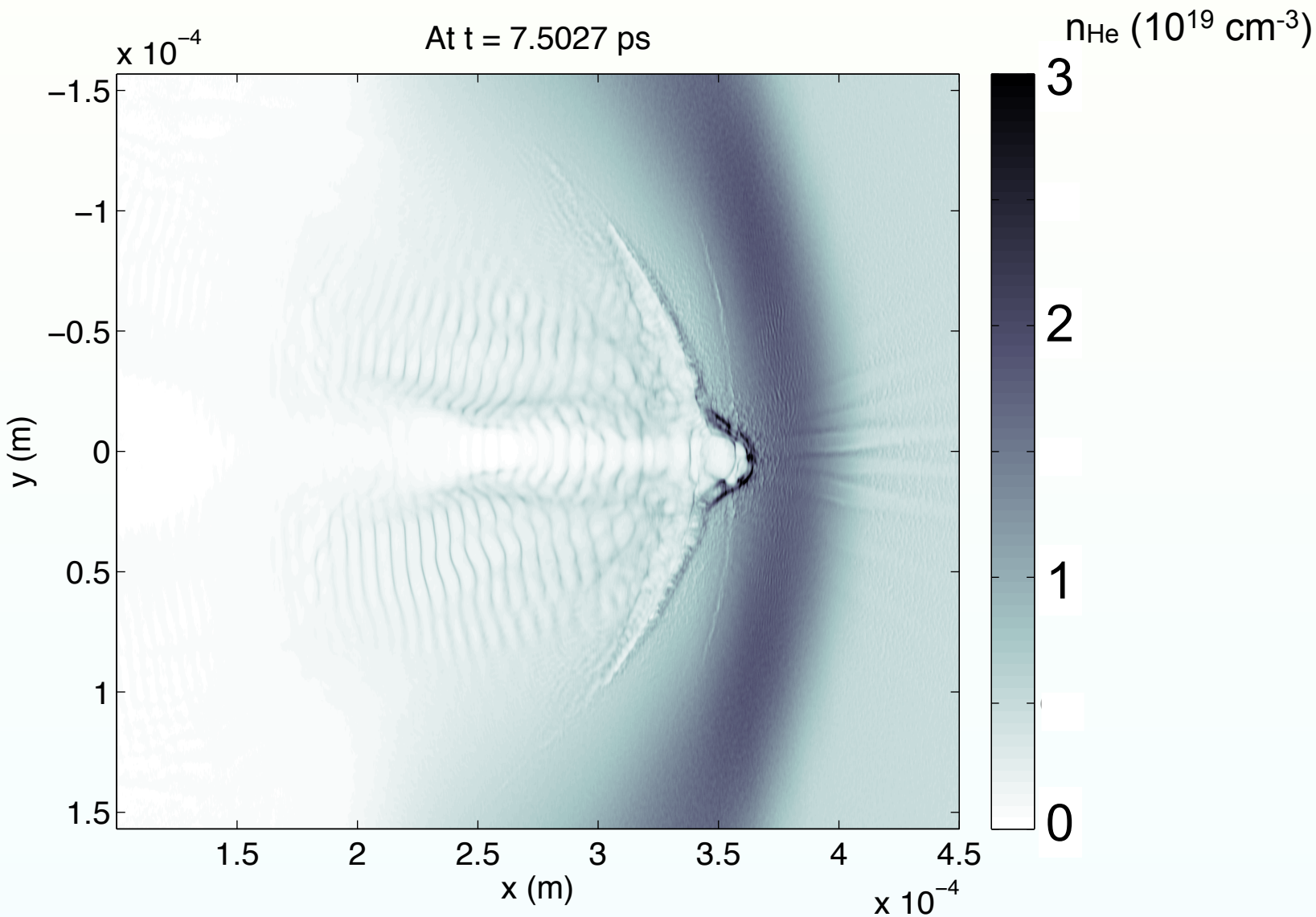
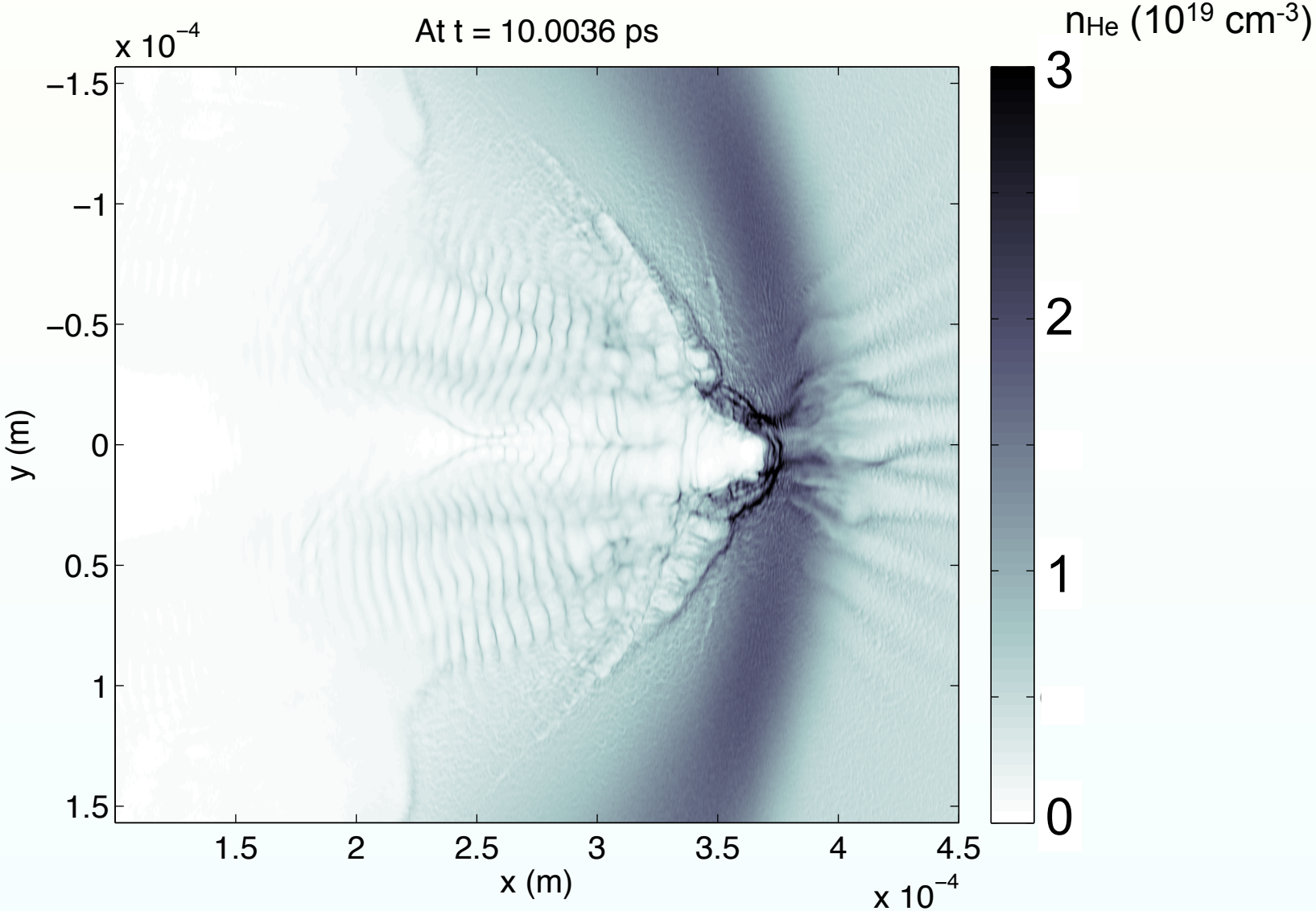


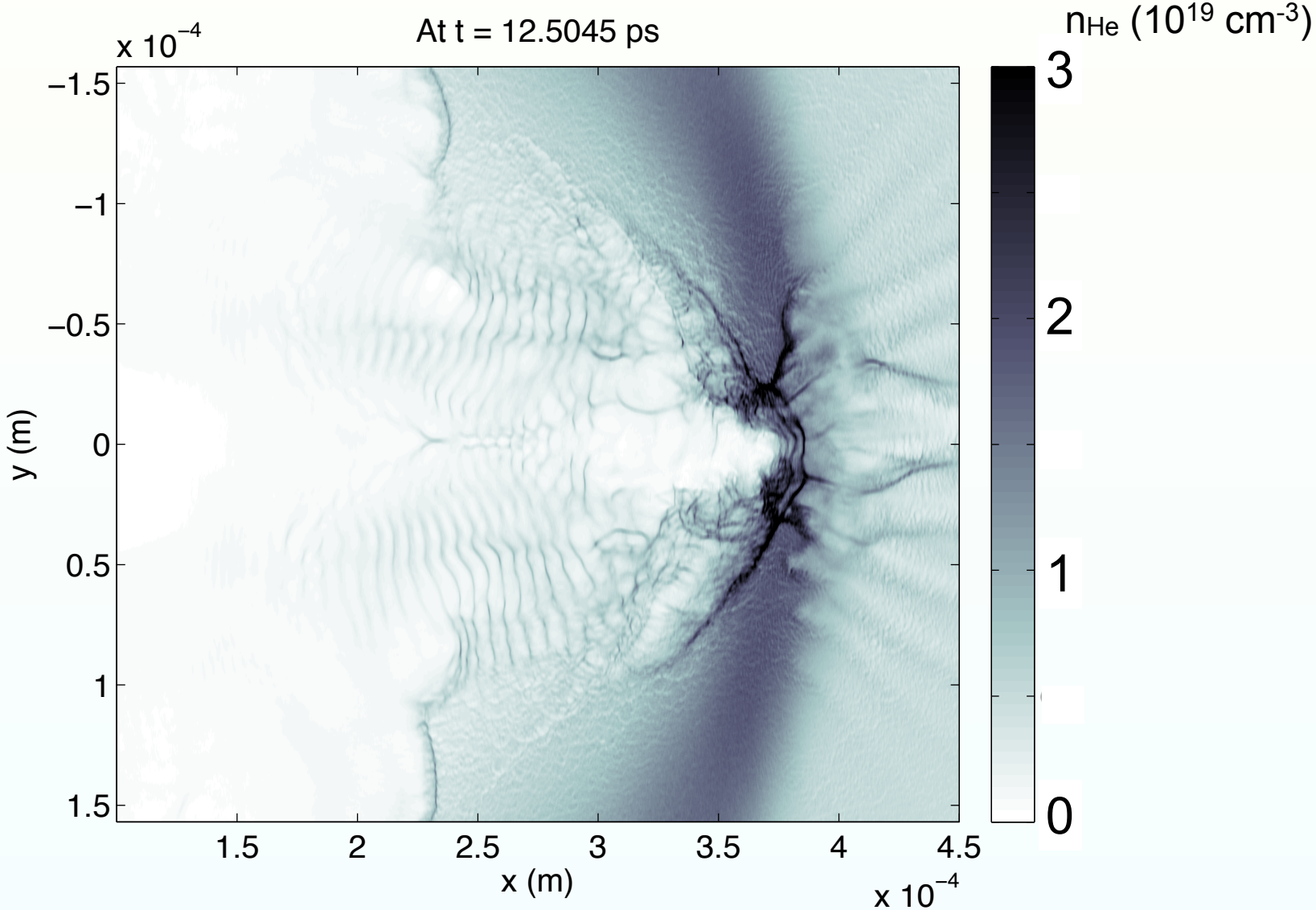
2D PIC with prepulse



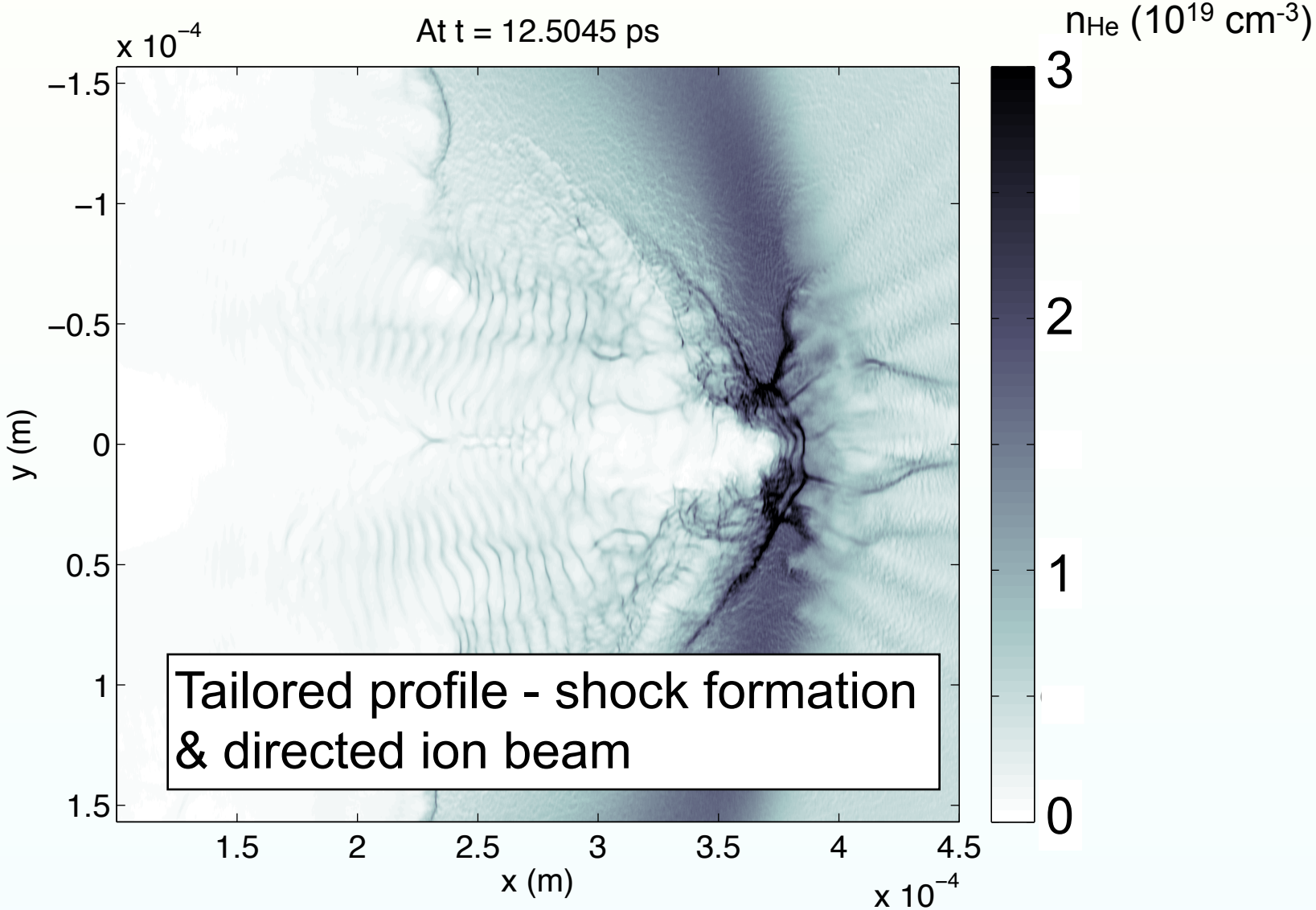
2D PIC with prepulse



2D PIC with prepulse



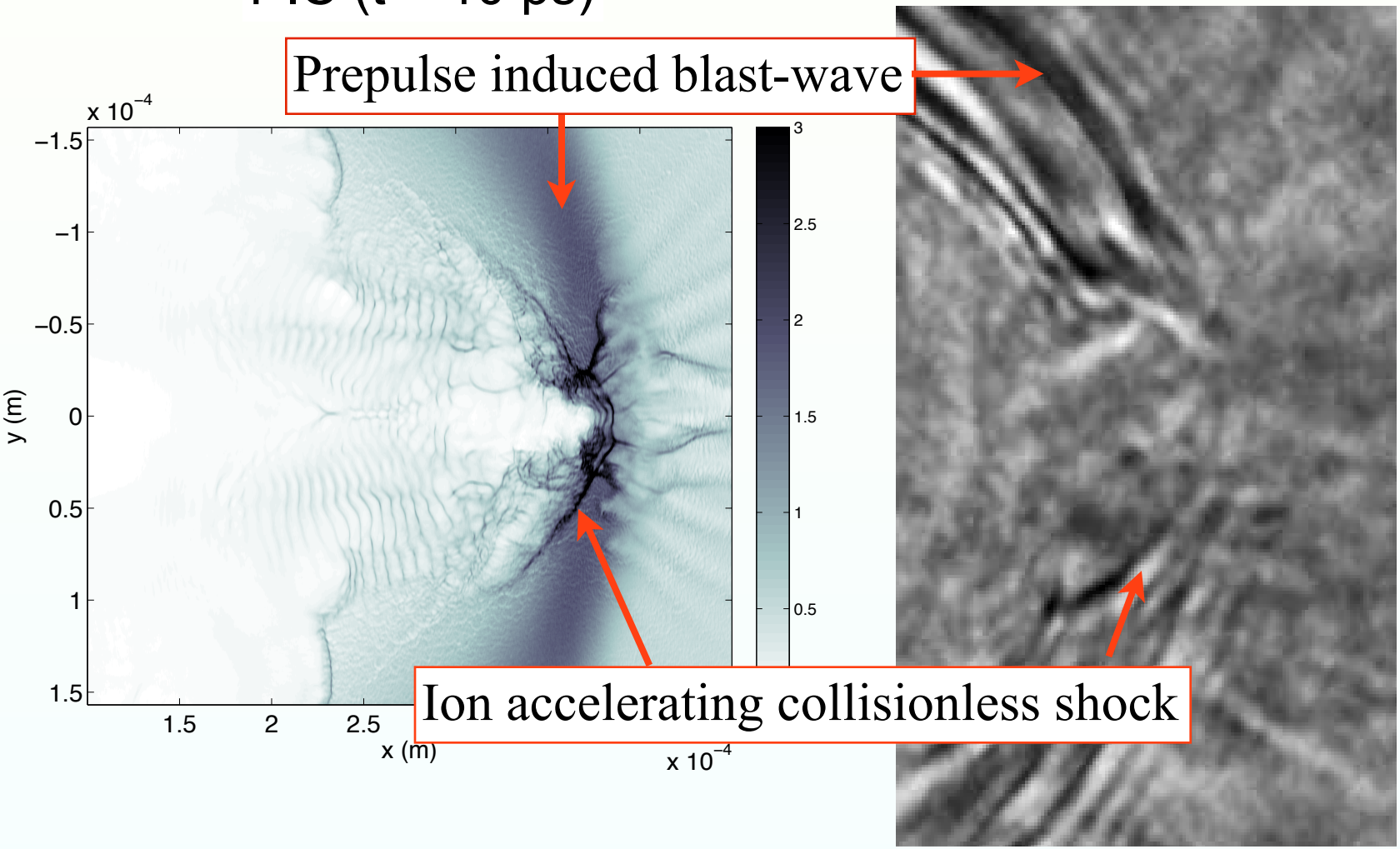
2D PIC with prepulse



PIC shows agrees with experiment

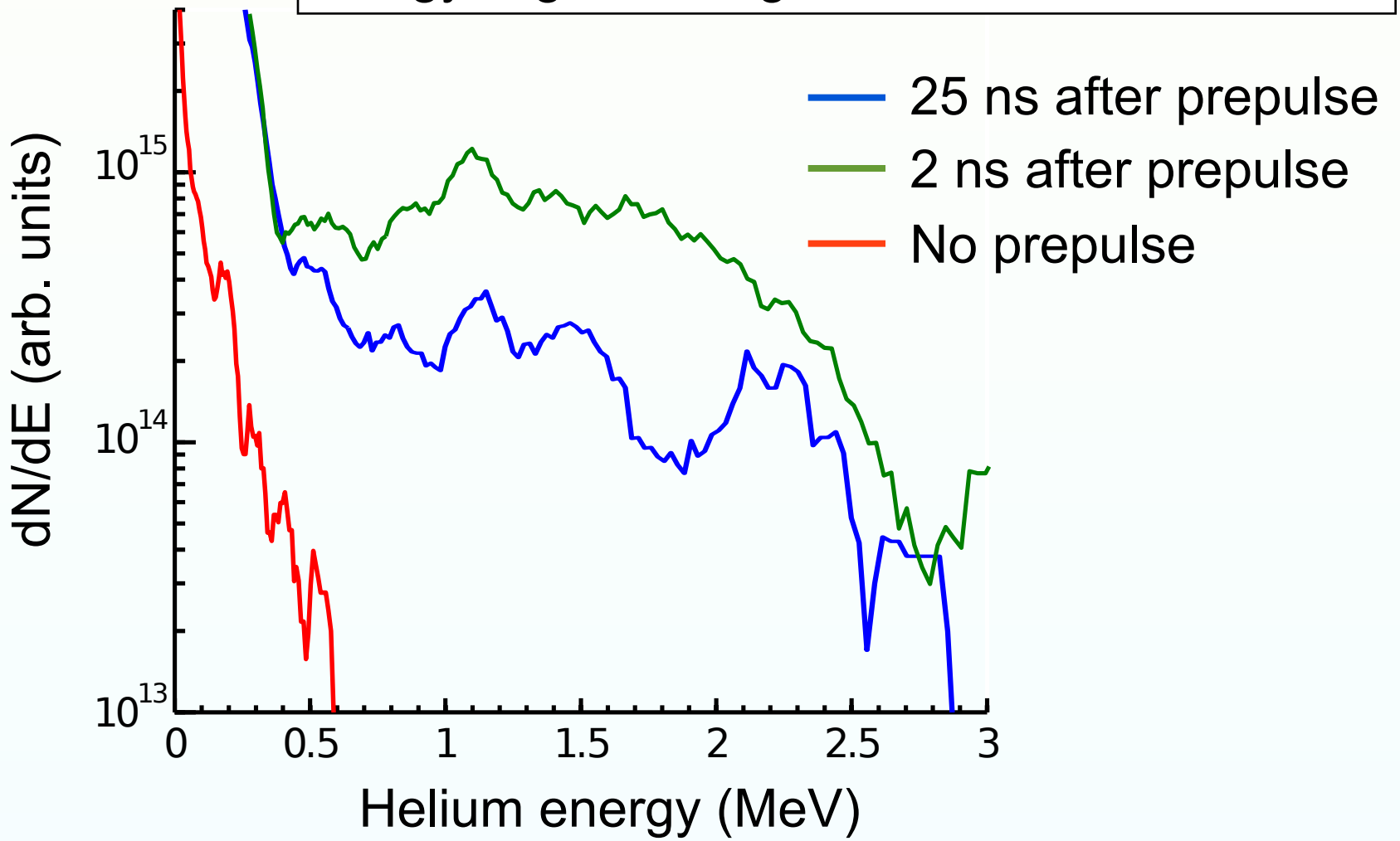
PIC (t ~ 10 ps)

Experiment (t ~ 100 ps)



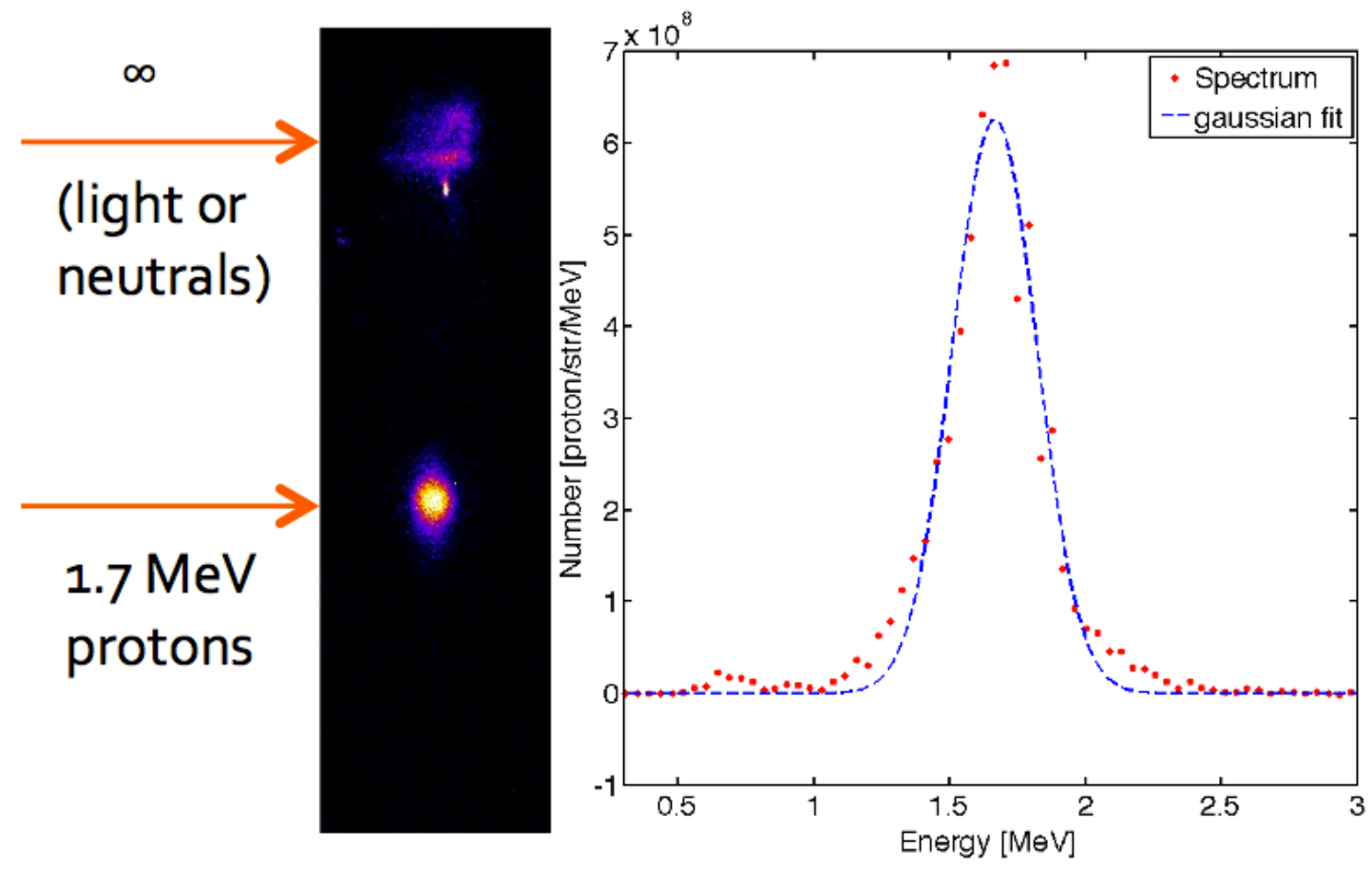
Can change beam by profile optimisation

Density profile optimisation to generate high energy, higher charge beams



Further work on proton beams

- Also appears to work for generation of proton beams - more mono-energetic beams & max energies up to ~3 MeV - work in progress

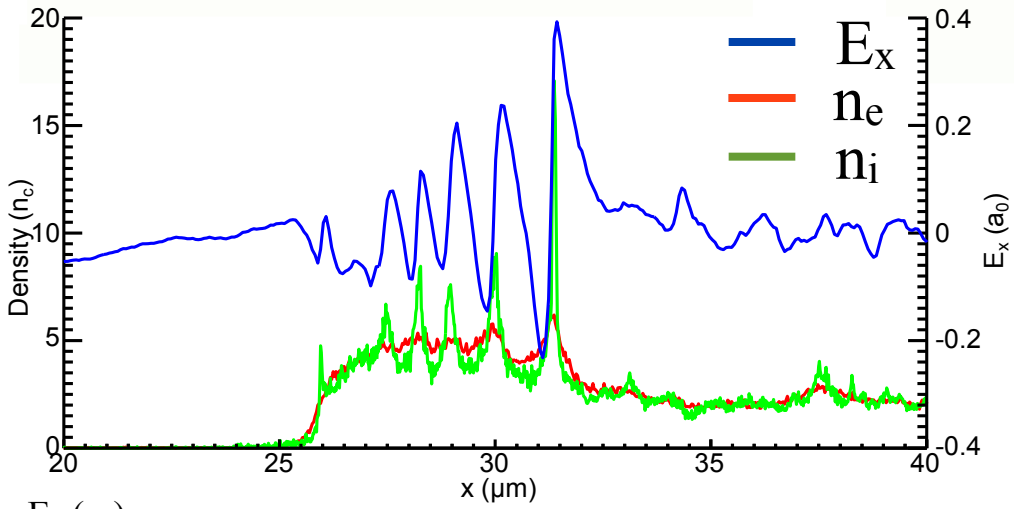


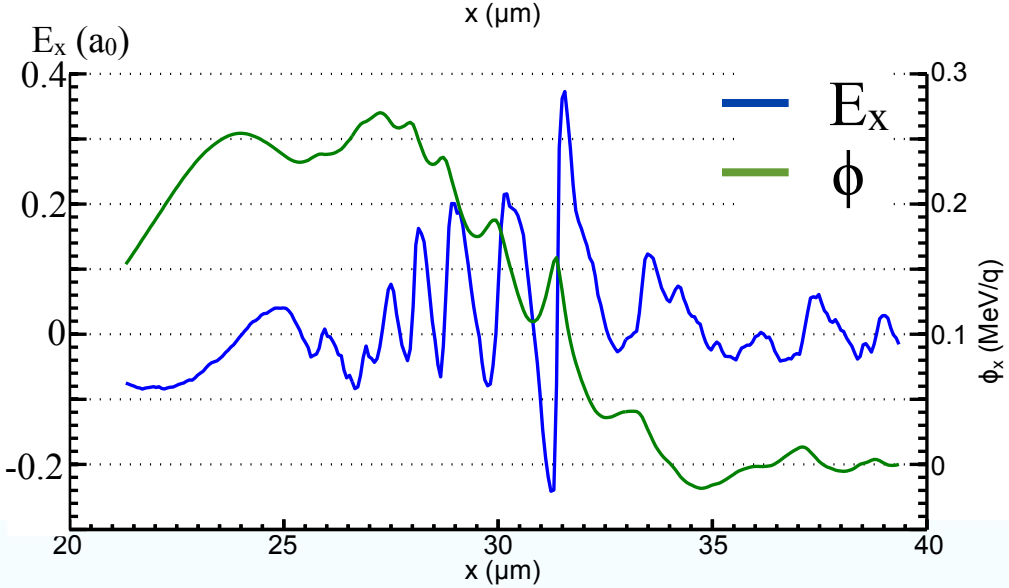
Summary

- Experimental demonstration of proton and helium beams from shock acceleration in gas jet targets
- Novel technique of all-optical shaping of overdense gas target using secondary pulse
- Optimising density profiles *essential* for ion generation

Numerical PIC simulations

- Lineouts through centre of box

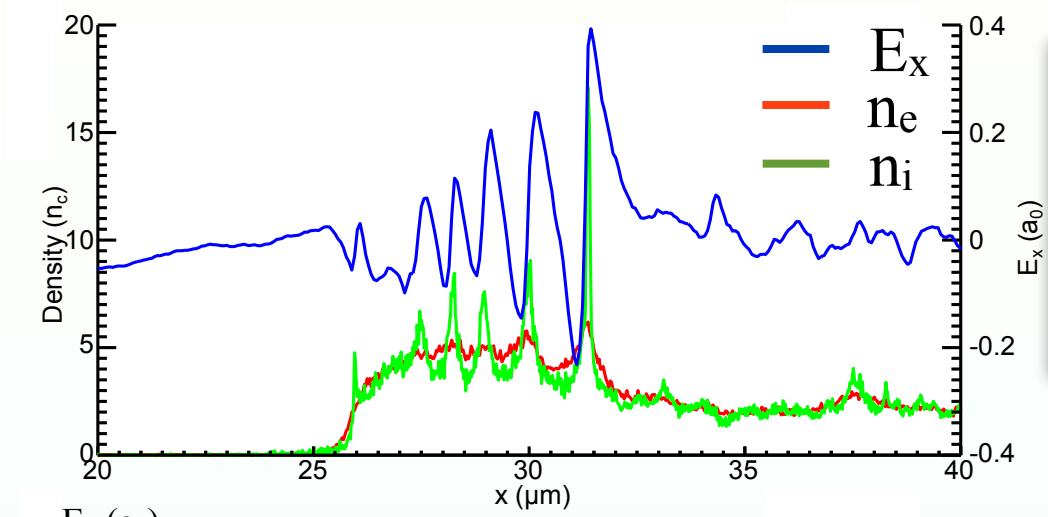


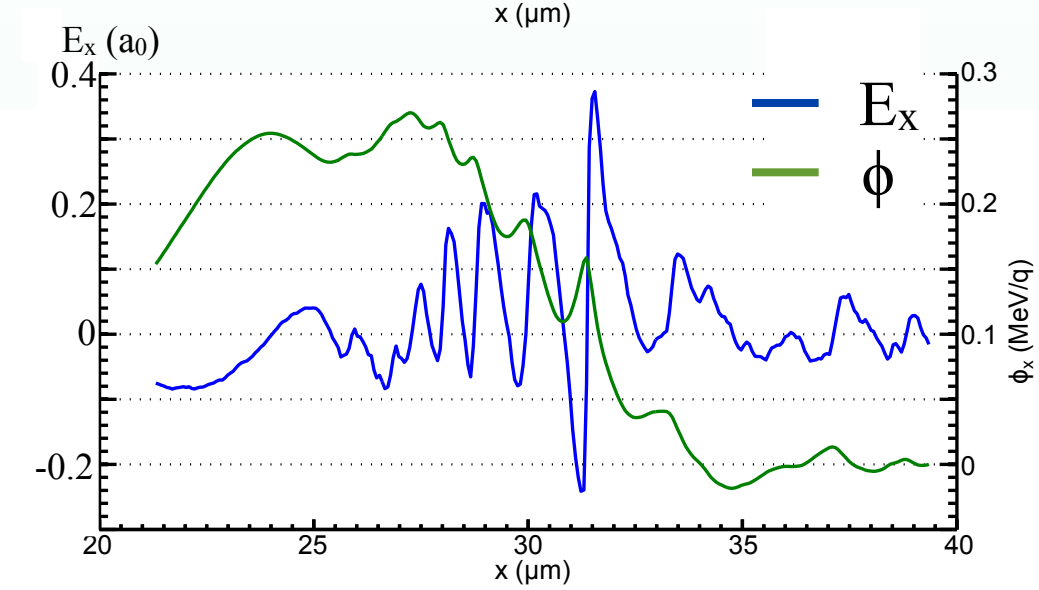


c)

Numerical PIC simulations

- Lineouts through centre of box



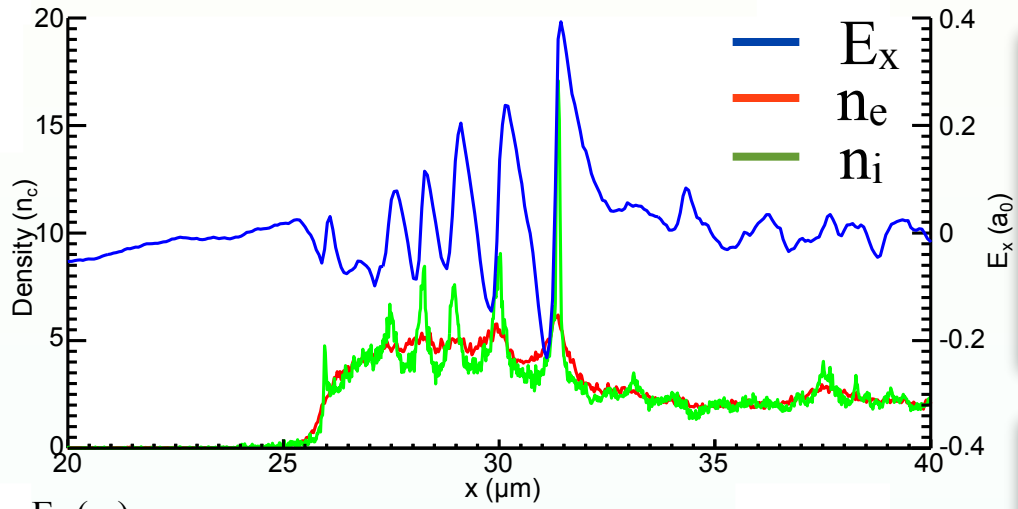


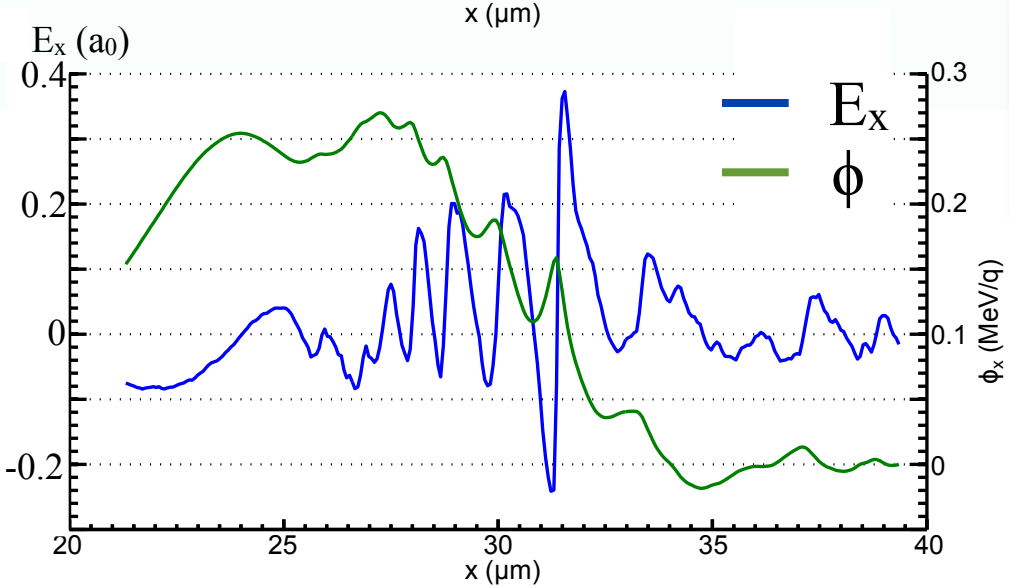
c)

Typical of **electrostatic collisionless shock** - a plasma shock driven by non-linear sound waves in hot plasma

Numerical PIC simulations

- Lineouts through centre of box





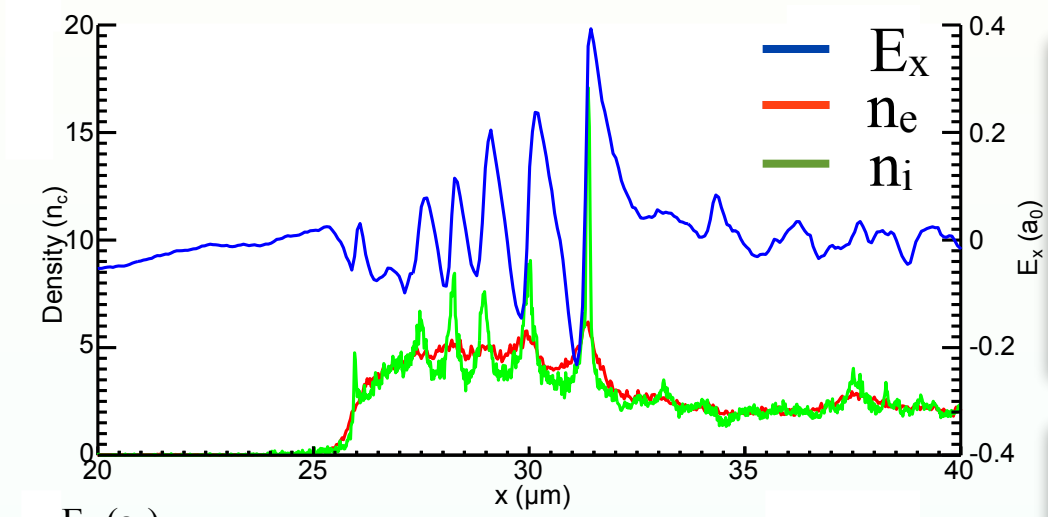
c)

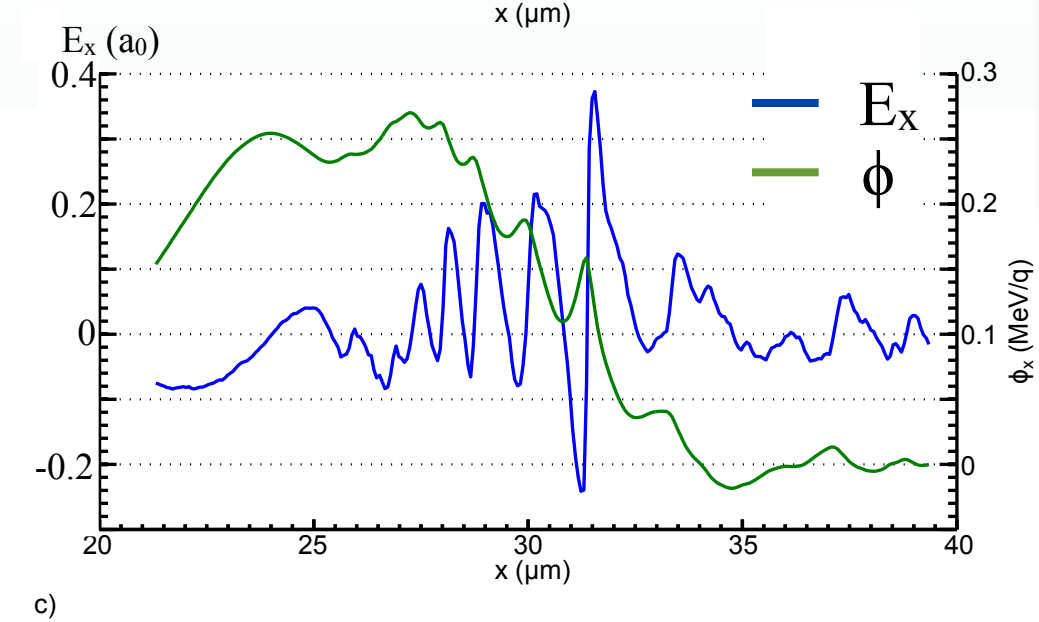
Typical of **electrostatic collisionless shock** - a plasma shock driven by non-linear sound waves in hot plasma

Hole-boring acts as piston driving **electrostatic collisionless shock wave**

Numerical PIC simulations

- Lineouts through centre of box





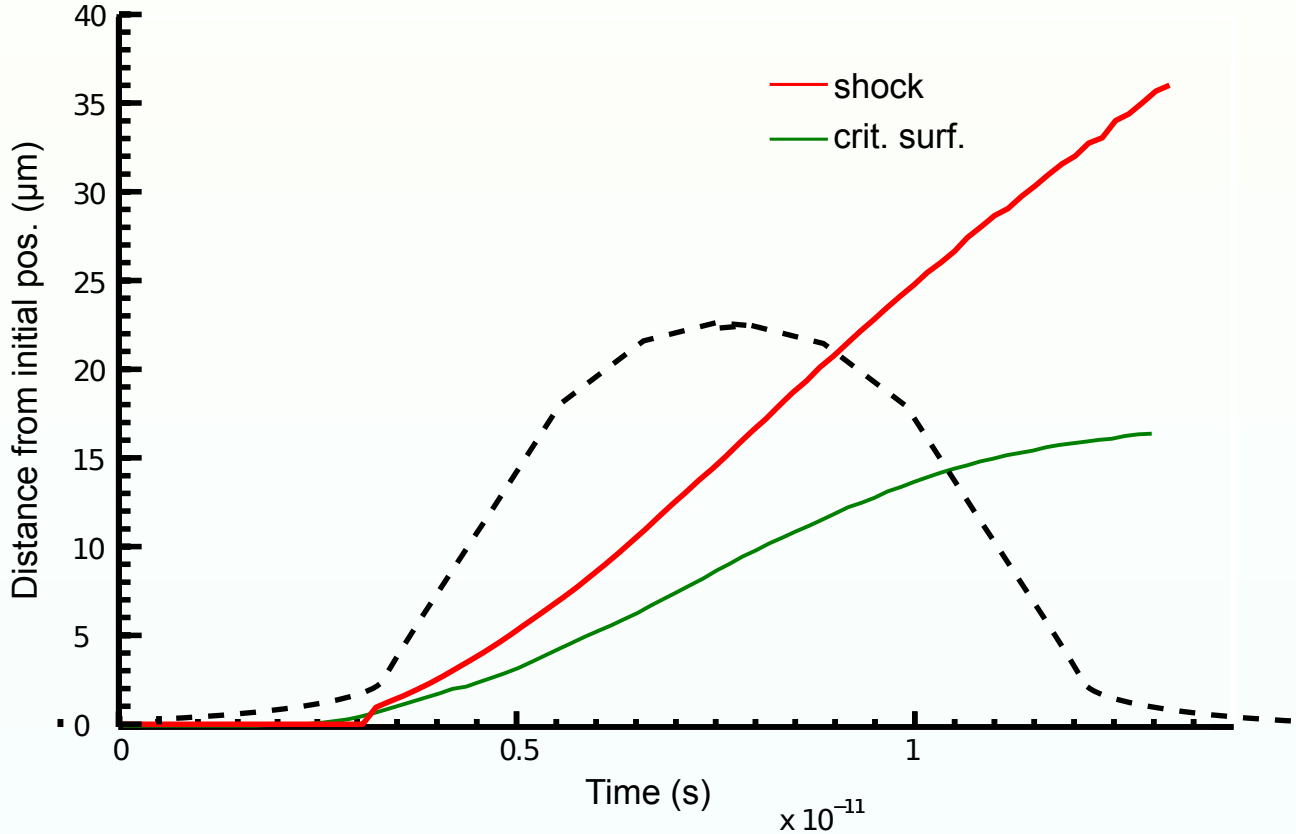
c)

Typical of **electrostatic collisionless shock** - a plasma shock driven by non-linear sound waves in hot plasma

Hole-boring acts as piston driving **electrostatic collisionless shock wave**

Protons are being accelerated by **reflection** at electrostatic **potential in shock**

Numerical PIC simulations



- **Shock moves ahead of hole-boring front**
  - **Reflected proton energies higher -> can reach higher proton energies at lower intensities**
- **Consistent with moving wave seen on optical probing**