

Shock-Wave Acceleration of Ions on OMEGA EP

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D. HABERBERGER,¹ A. PAK,² A. LINK,² P. K. PATEL,²
F. FIUZA,³ S. YA. TOCHITSKY,⁴ C. JOSHI⁴, and D. H. FROULA,¹

¹University of Rochester, Laboratory for Laser Energetics,
²Lawrence Livermore National Laboratory, ³SLAC National Accelerator Laboratory,
⁴University of California, Los Angeles

Summary

Tailored plasma profiles suitable for shock-wave acceleration (SWA) on OMEGA EP have been produced and characterized

- SWA experiments at the University of California, Los Angeles (UCLA)
 - use a 10-μm laser in a H₂ gas jet
 - produce 20-MeV protons with narrow energy spreads
 - have a normalized vector potential of $a_0 < 2.5$
- Plasma profiles with a sharp rise to a near-critical peak density and a long exponential decay are key to successful SWA
- SWA plasma profiles have been produced on OMEGA EP using the thermal emission from an Au-driven target to irradiate 2-μm CH foils

E21747b

The plasma density profile strongly affects the spectrum of the accelerated ions

OSIRIS

Longitudinal momentum (m_ec)

$x_1(\frac{c}{\omega_0})$

Ions (arbitrary units)

$x_1(\frac{c}{\omega_0})$

Sheath fields that exist at the sharp plasma-vacuum boundary can smear the energy spread of accelerated ions.

*TNSA: target normal-sheath acceleration

E21748e

Optical probing shows clear evidence of an asymmetric expansion of the 2-μm CH foil target

Angular filter refractometry (AFR)* measures the refraction of a probe beam passing through a plasma

0.75 ns 1.00 ns 1.25 ns

y (μm) x (μm) x (μm)

E24650a

*D. Haberberger et al., Phys. Plasmas 21, 056304 (2014).

Lasers incident on overcritical plasmas can create conditions for shock-wave generation

Laser-heating and ponderomotive push

Launch-density perturbation

Shock-propagation ion reflection

Plasma density (n/n_c)

$x_1(c/\omega_0)$

Electric field (GV/cm)

$x_1(c/\omega_0)$

Ion reflection $V_{\text{ref}} = 2V_{\text{sh}} - V_i$

E21748d

*F. Fiua et al., Phys. Rev. Lett. 109, 215001 (2012).

A sharp rise to overcritical densities with a longer exponential tail can be created with a gas jet for 10-μm light

Gas plume

CO₂ laser

Ion beam

Plasma density ($\times 10^{19} \text{ cm}^{-3}$)

x distance (μm)

Proton spectra

Normalized proton yield

Proton energy (MeV)

mm • mrad

CO₂ systems are limited in peak power as compared to 1-μm lasers.

E21749b

*D. Haberberger et al., Nature Phys. 8, 95 (2012).

A comparison between the experimental AFR images and simulated AFR images using the hydrodynamic profiles shows an optimal peak density at ~1 ns

$n_c = 5 \times 10^{21} \text{ cm}^{-3}$

0.75 ns 1.00 ns 1.25 ns 2.00 ns

y (μm) x (μm) x (μm)

E24651a

Simulations predict strong scaling of the SWA mechanism with laser intensity

Particle-in-cell simulations

Proton energy (MeV)

Laser a_0

Scaling the SWA mechanism to the 1-μm OMEGA EP Laser System allows for the production of narrow-energy-spread ion beams in the 80- to 150-MeV/amu range.

E21751b

*F. Fiua et al., Phys. Rev. Lett. 109, 215001 (2012).

Scaling SWA to the 1-μm-wavelength range requires a tailored high-density profile

High-power IR 400 J, 1 ps, $3 \times 10^{19} \text{ W/cm}^2$

Low-power UV 1 kJ, 1 ns, 10^{14} W/cm^2

1-μm-thick CH foil

Au target

Plasma density ($\times 10^{21} \text{ cm}^{-3}$)

y (μm)

0.75 ns 1.00 ns 1.50 ns 2.00 ns

2-D HYDRA simulations

- UV absorption in Au (~90%)
- plasma thermal emission (175 eV)*
- absorption in 2-μm CH foil (C K-shell)
- hydrodynamic expansion

*Static pinhole camera array with differential filters used to guide blackbody temperature

E24649a

In the presence of a plasma, certain angle ranges of the refracted light pass through the filter and form bands in the image plane

Target chamber center (TCC) object plane

Foil target

Fourier plane

Image plane

AFR maps the refraction of the probe beam at TCC to contours in the image plane.

E22129p

*D. Haberberger et al., Phys. Plasmas 21, 056304 (2014).

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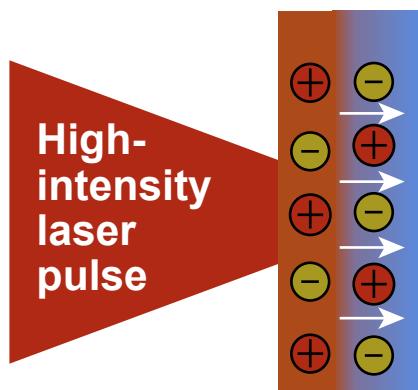


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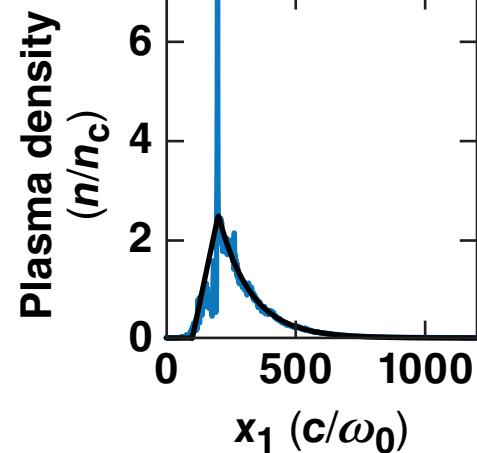
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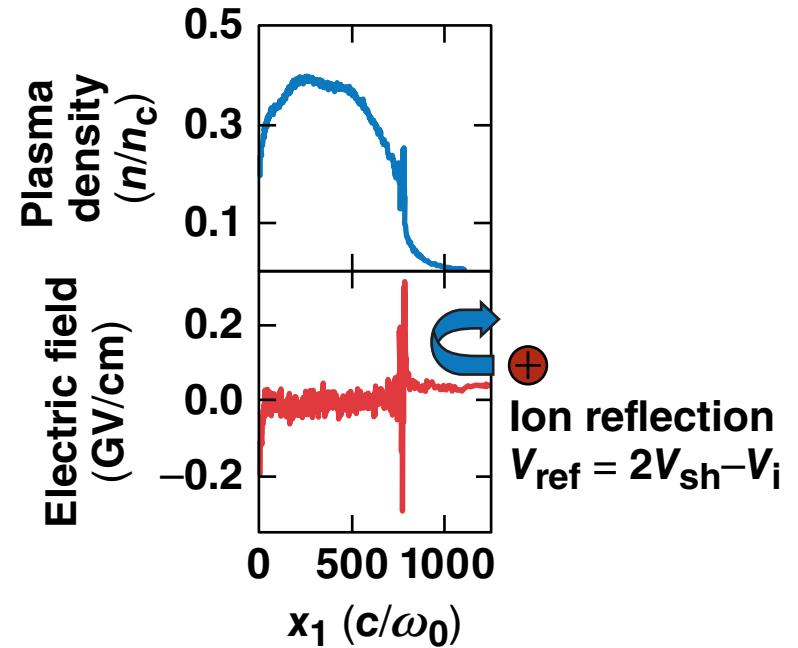
Laser-heating and ponderomotive push



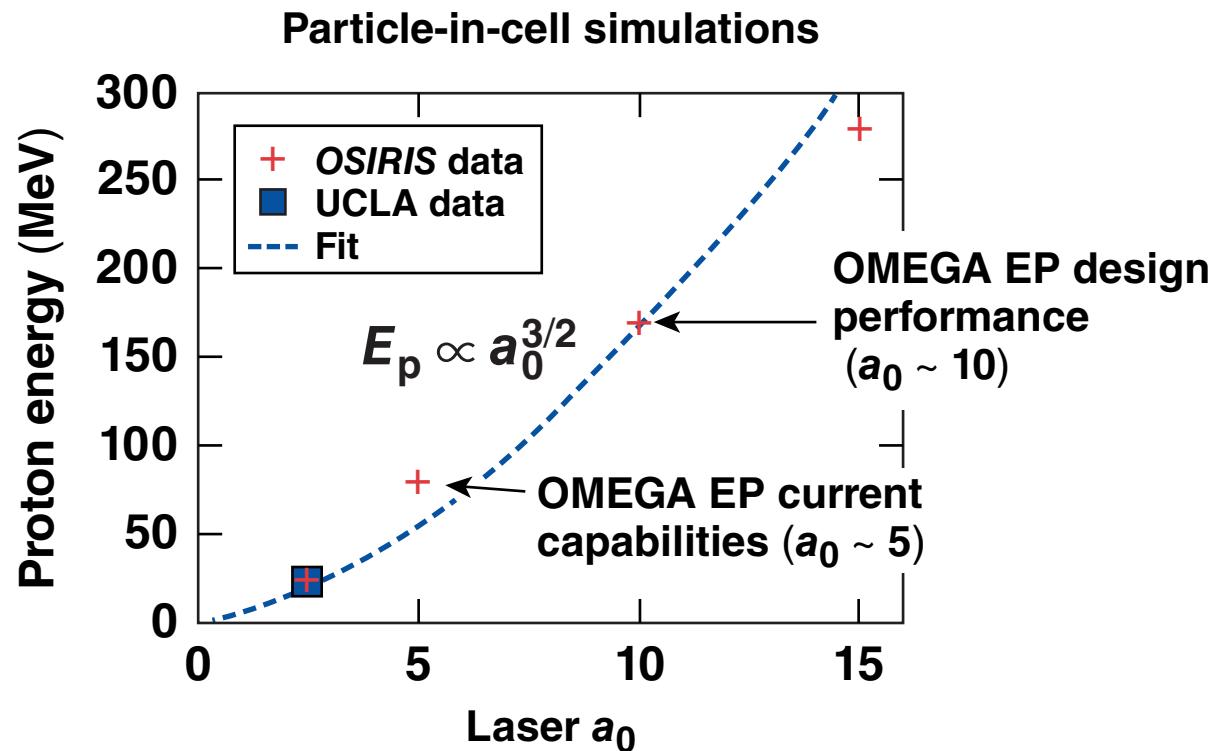
Launch-density perturbation



Shock-propagation ion reflection

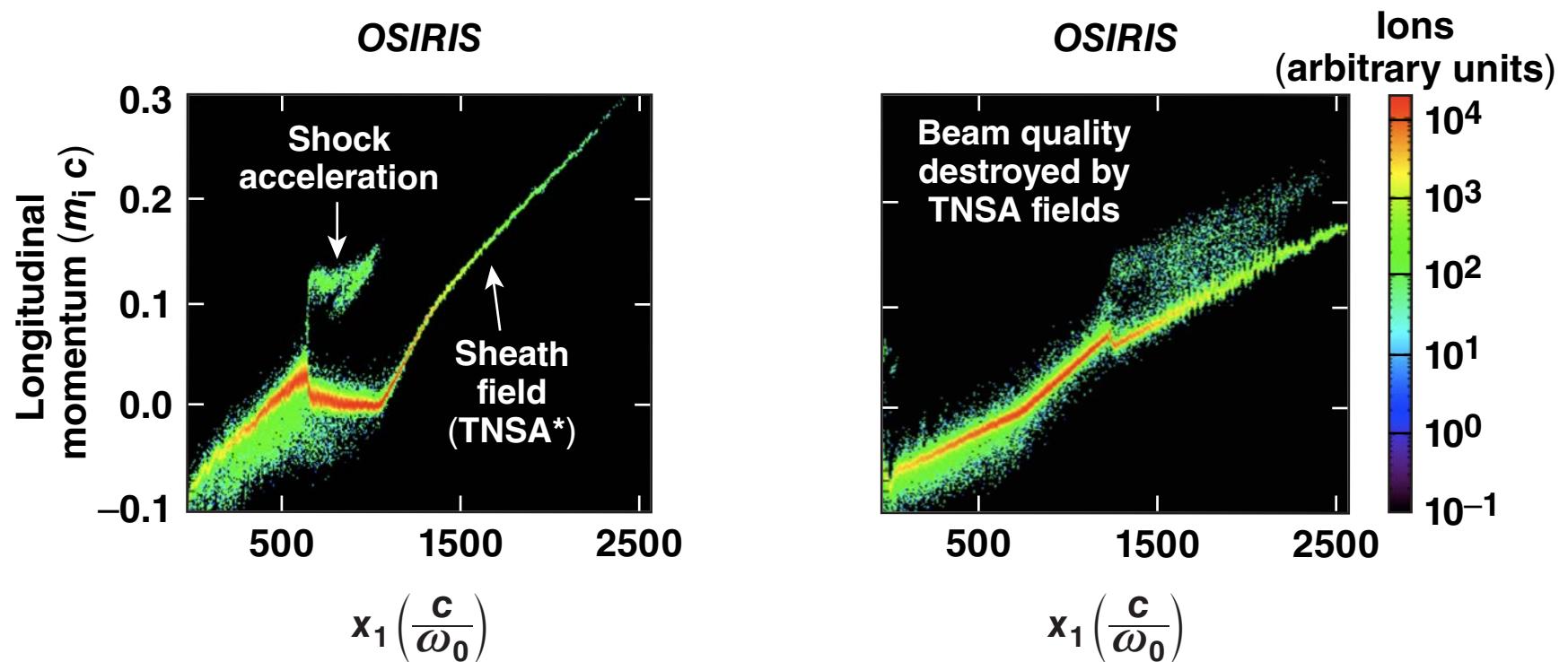


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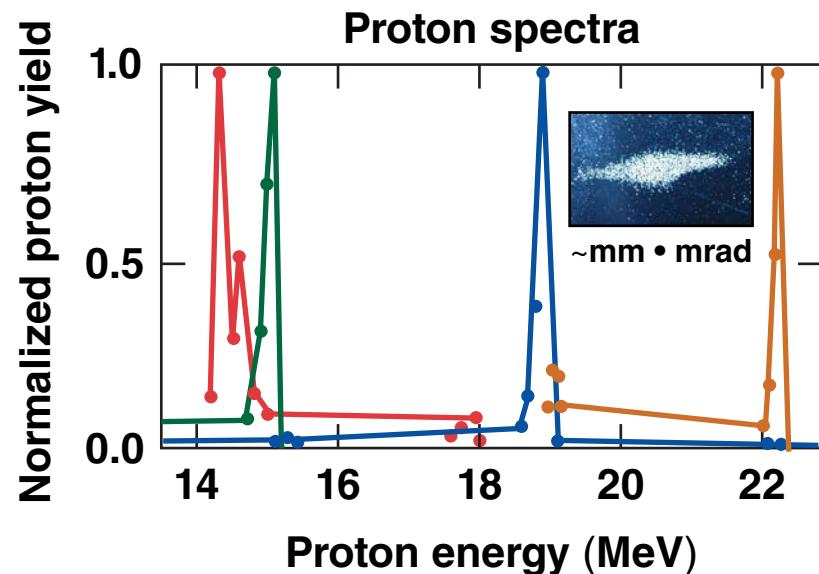
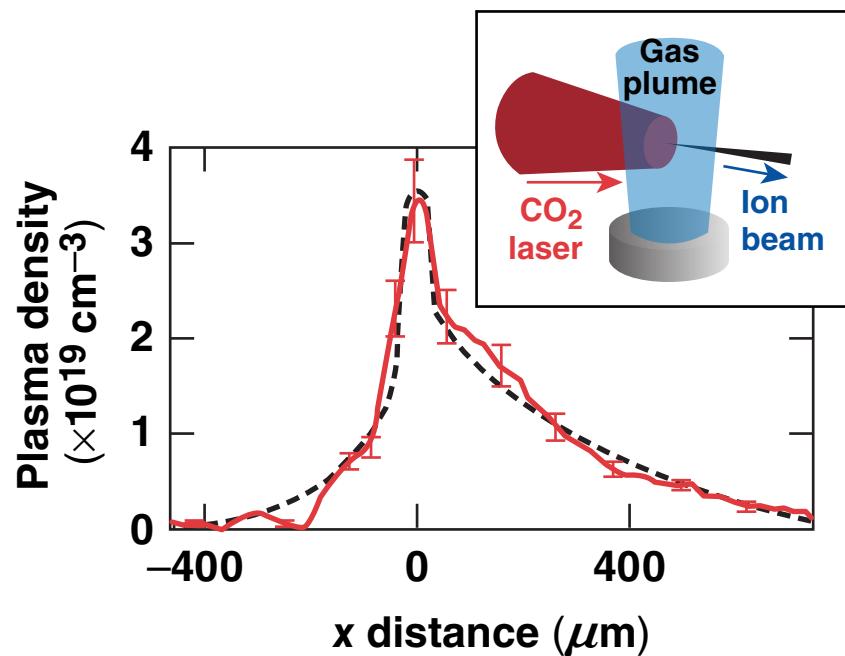
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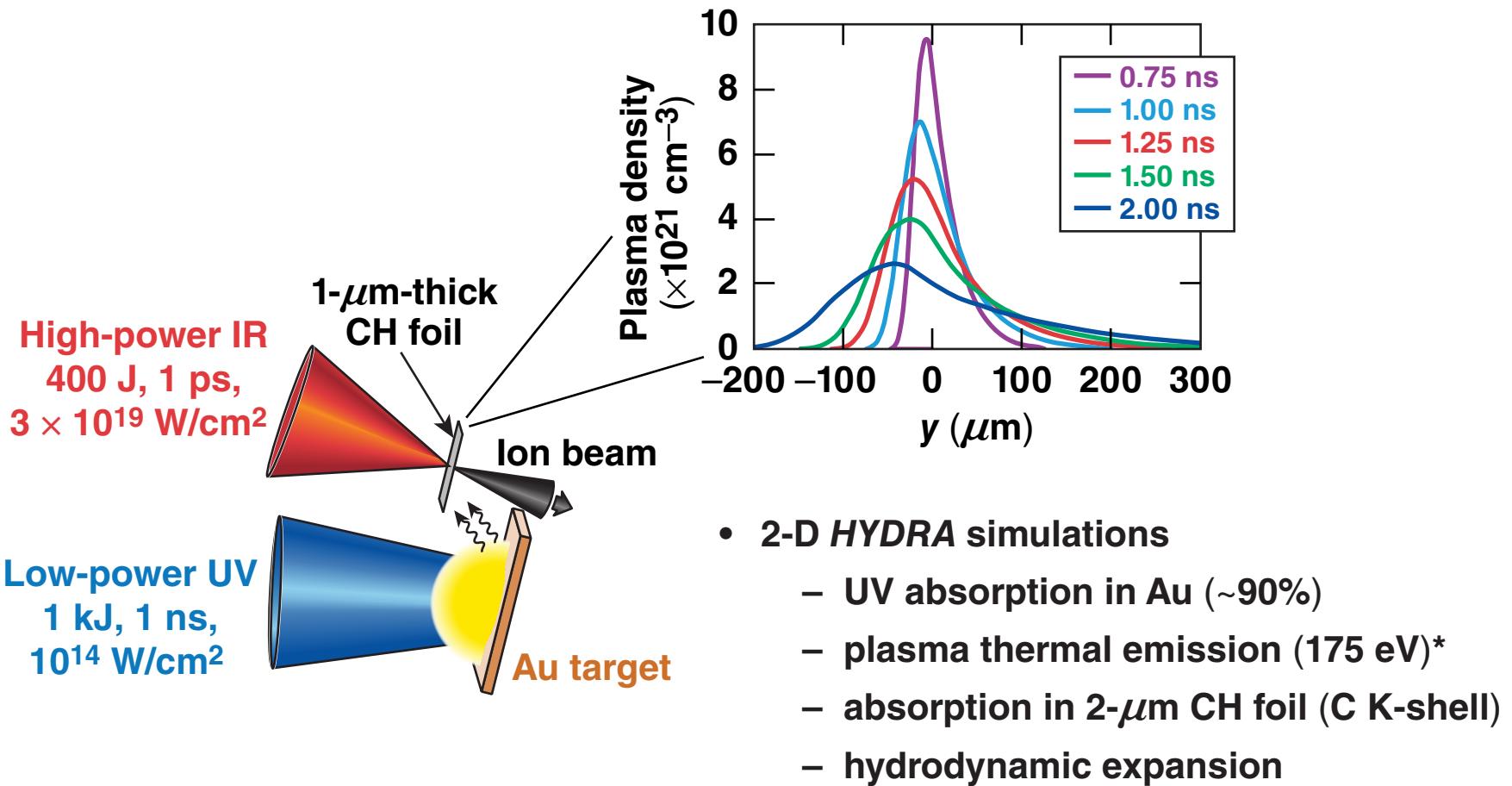
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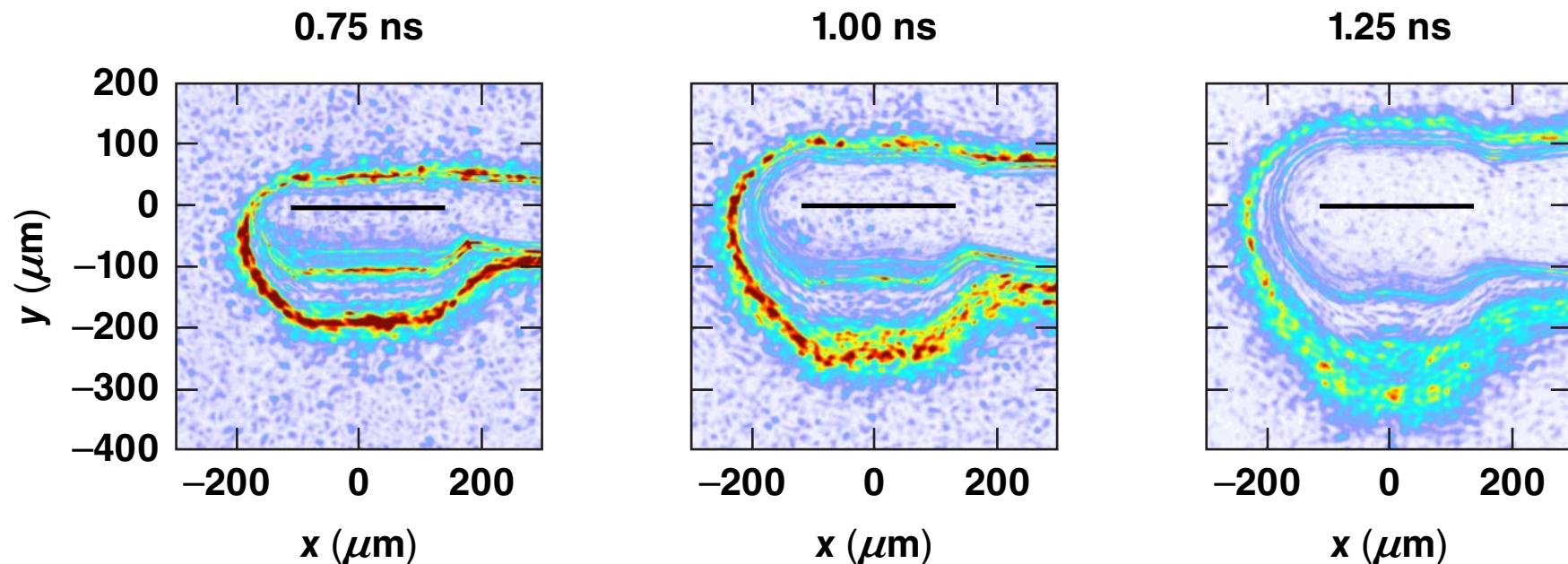


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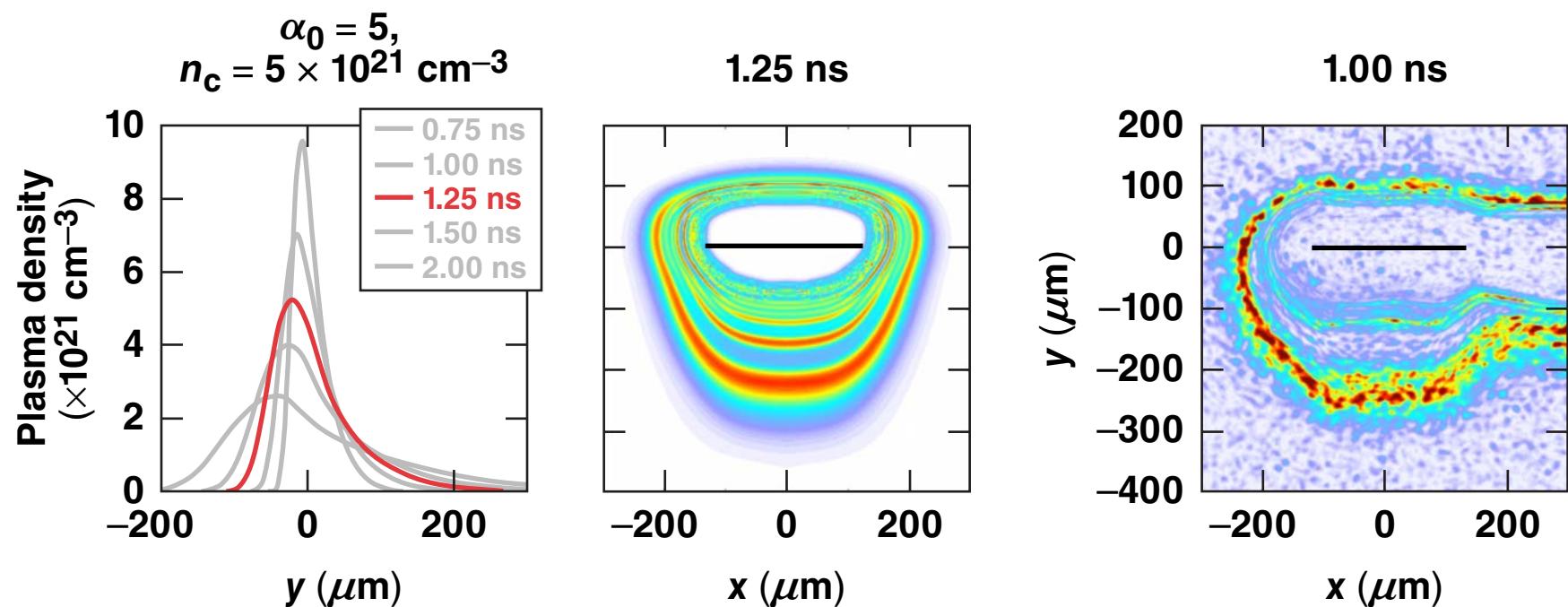


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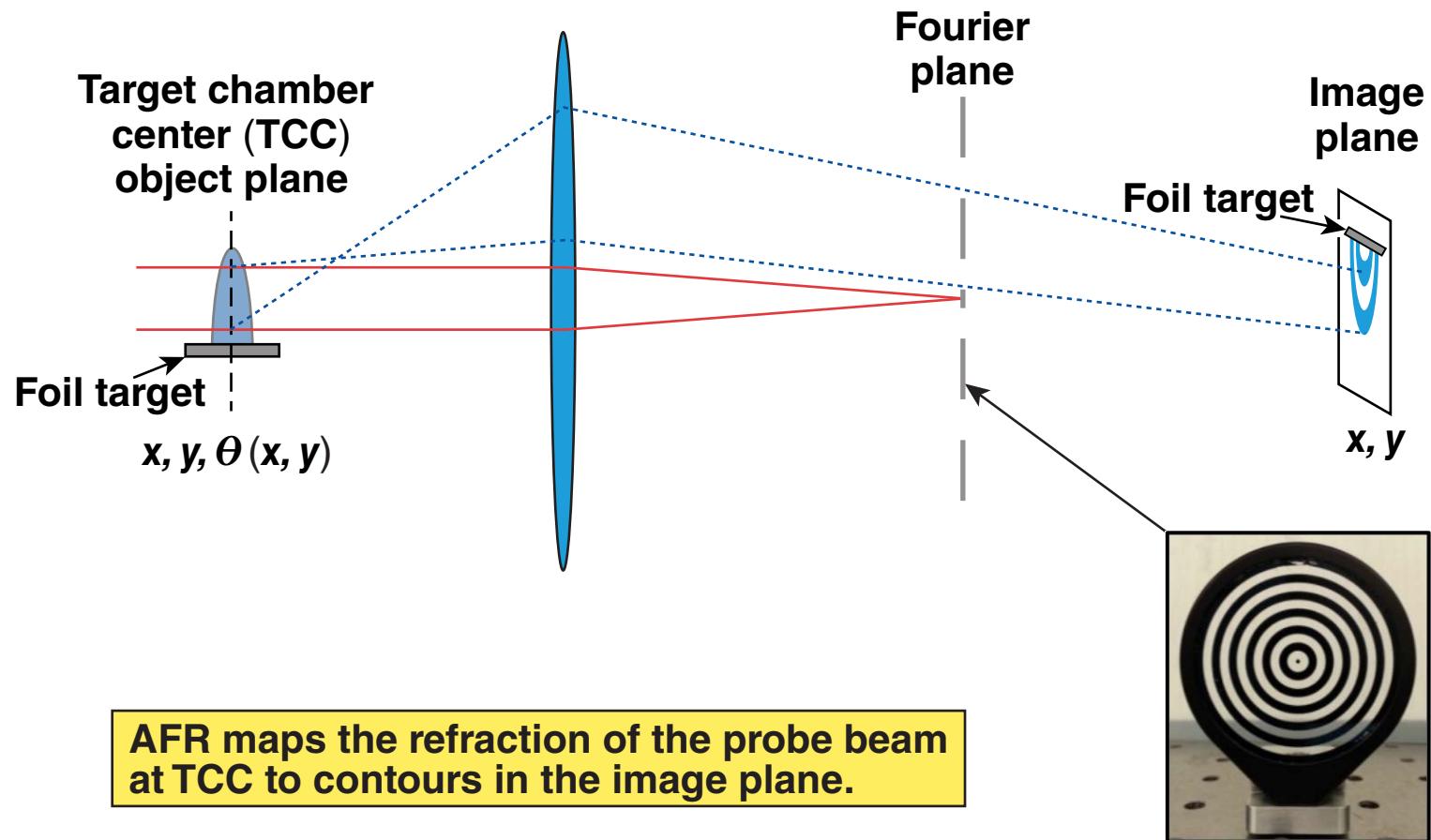


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