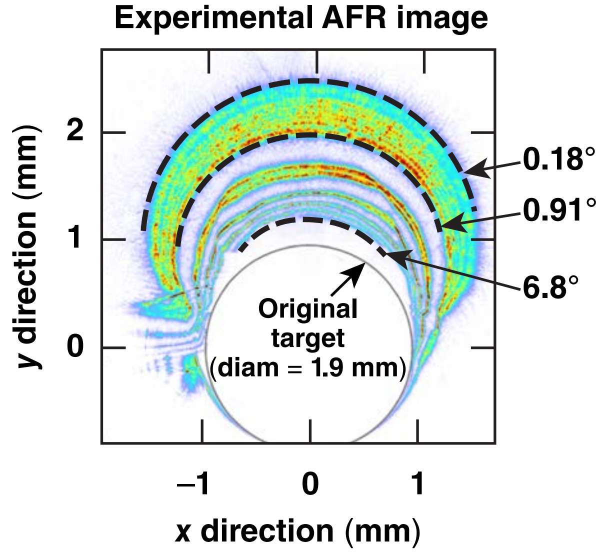
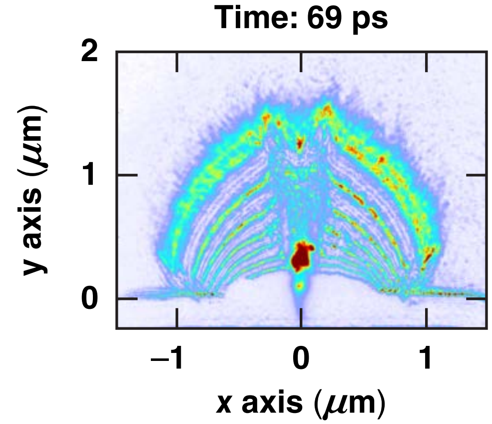
Optical Probing Measurements on OMEGA EP

UR LLE

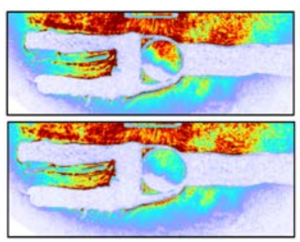
Direct drive (underdense hydro)



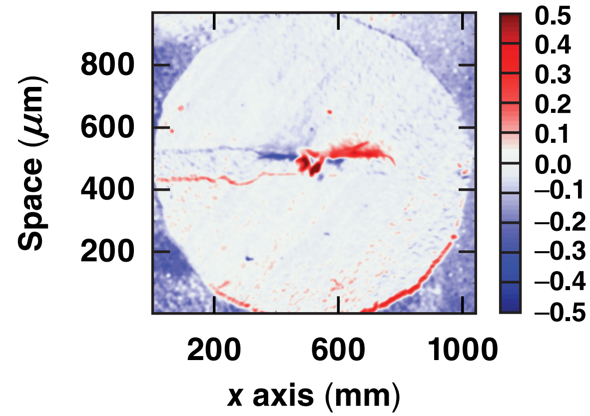
Short-pulse physics (channeling)



Inertial confinement fusion (ICF)
(magnetized hohlraum)



Astrophysics
(magnetic reconnection)



D. Haberberger
University of Rochester
Laboratory for Laser Energetics

Omega Laser Facility
Users' Group Workshop
Rochester, NY
23–25 April 2014

Summary

The fourth-harmonic (263-nm) probe diagnostic system provides an opportunity to study the plasma conditions for a variety of high-energy-density (HED) and basic physics studies

UR LLE

- The 4ω diagnostic system was activated near the beginning of 2013 on the OMEGA EP Laser System
- A novel diagnostic, angular filter refractometry (AFR), was developed to study plasma density profiles up to 10^{21} cm^{-3} (UV-irradiated targets and short-pulse channeling)
- Polarimetry has been recently activated to measure laser-generated magnetic fields (magnetized ICF and short-pulse magnetic reconnection)
- Interferometry is at the conceptual stage to extend the low end of the measurement range for plasma density profiles

E22829

Collaborators

R. Boni, M. Barczys, J. Brown, R. Huff, S. X. Hu, S. Ivancic, R. G. Roides, M. Bedzyk, R. S. Craxton, F. Ehrne, C. Stoeckl, E. Hill, R. K. Jungquist, J. Magoon, D. Mastrosimone, J. Puth, W. Seka, M. J. Shoup III, W. Theobald, D. Weiner, J. D. Zuegel, and D. H. Froula

University of Rochester
Laboratory for Laser Energetics

J. Moody, D. Turnbull, B. Pollock, and S. Ross

Lawrence Livermore National Laboratory

A. Harvey-Thompson

Sandia National Laboratory

Outline

- 4ω diagnostic overview
- Plasma density profile
- Laser-generated magnetic fields
- Ongoing work

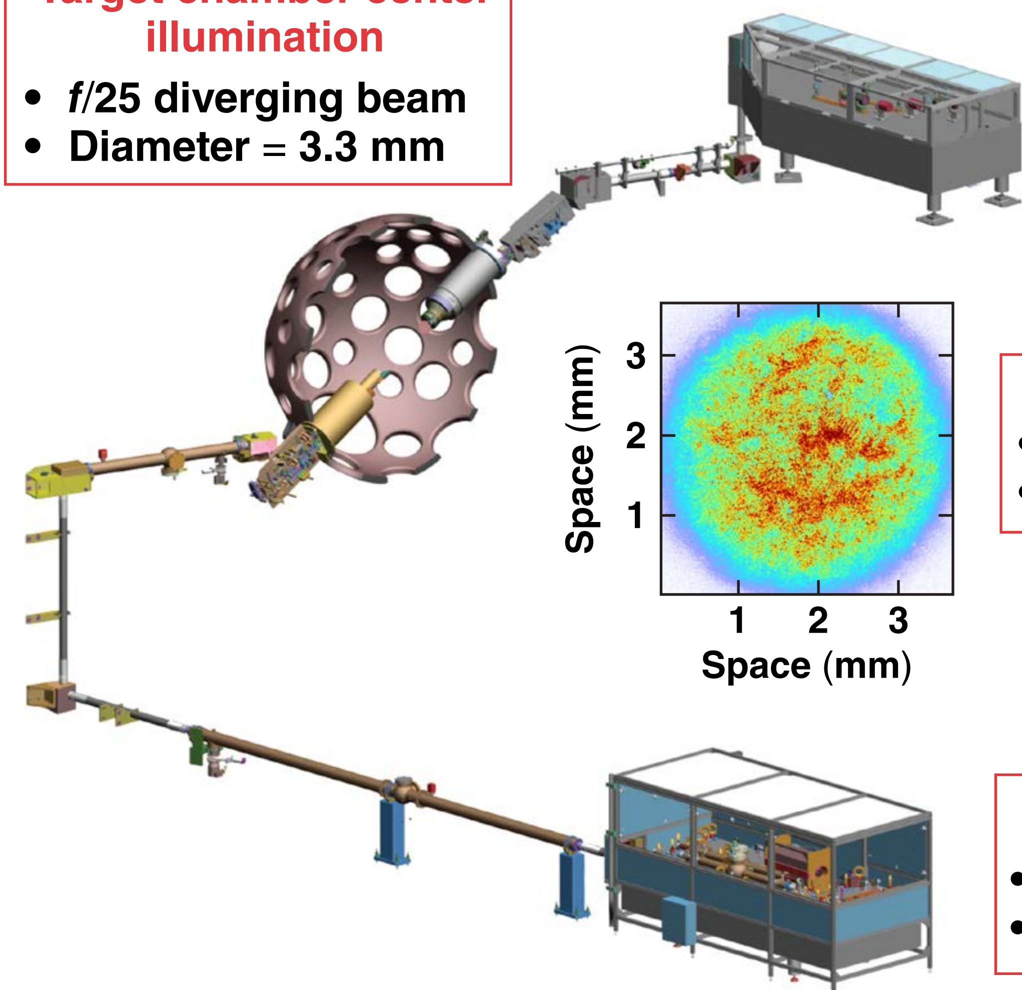
The OMEGA EP 4ω probe laser system delivers a high-quality beam at target chamber center (TCC) that is collected at *f*/4 to access high plasma densities

Target chamber center illumination

- *f*/25 diverging beam
- Diameter = 3.3 mm

Diagnostic table

- 5-μm resolution
- 3.7 × 3.7-mm field of view



Timing

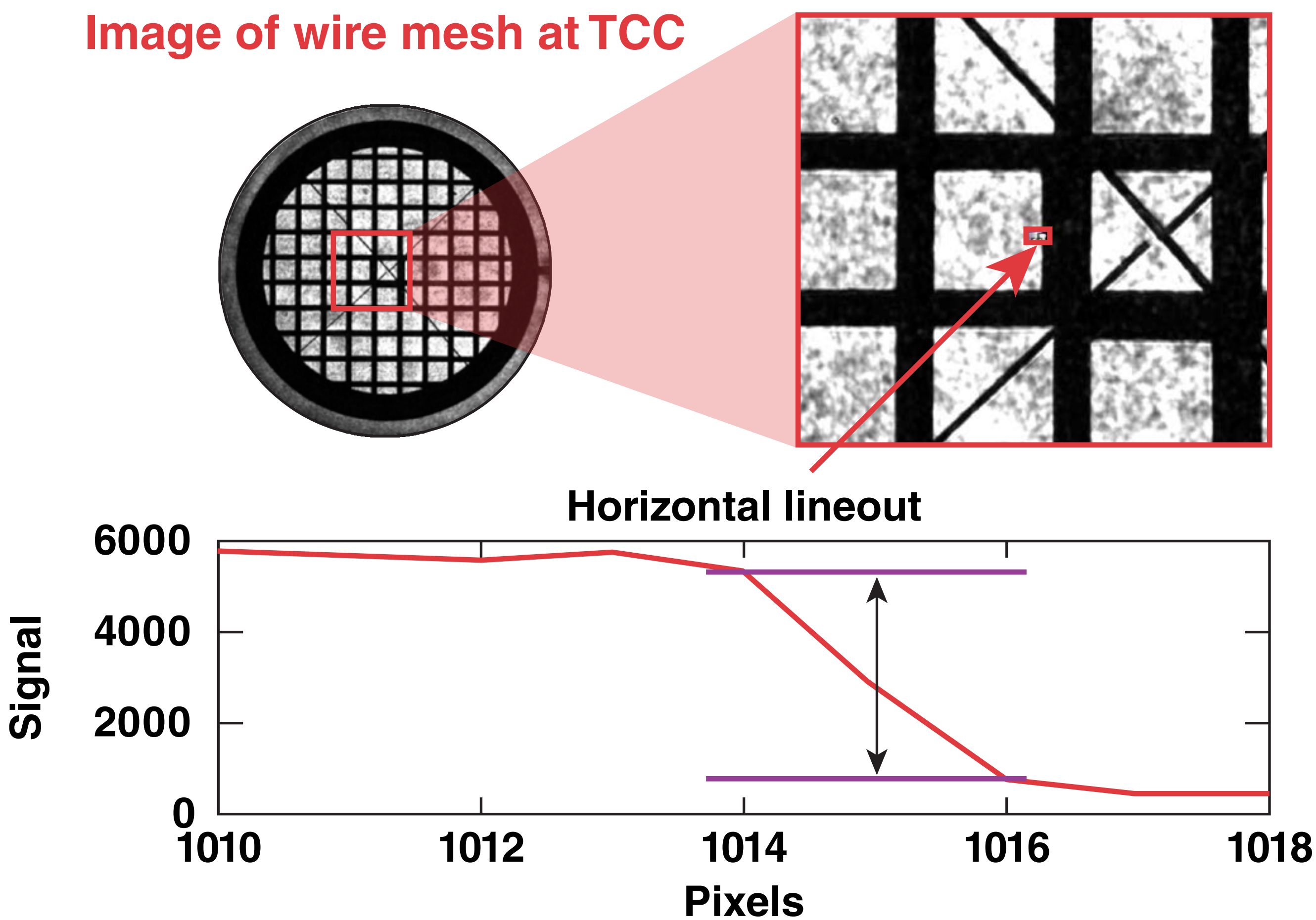
- ±50-ps accuracy (pre-shot)
- ±20-ps post-shot measurement

Nd:glass laser

- 4ω (263 nm) ~20 mJ
- Pulse width = 10 ps

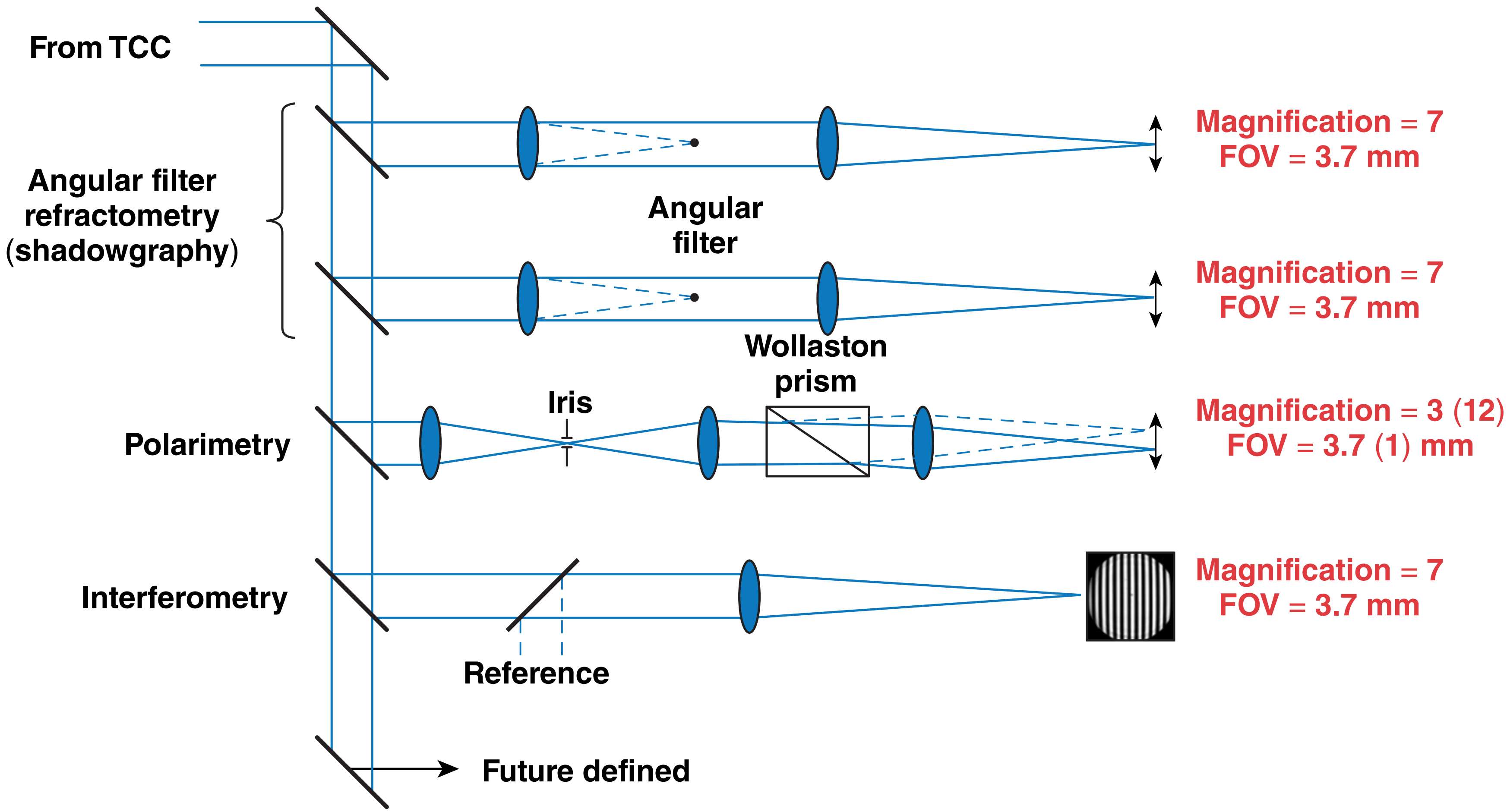
E22054c

A wire mesh at TCC demonstrates 5-μm imaging resolution over a 3-mm field of view (FOV)



The rising edge (10% to 90%) of a shadow occurs over 2 pixels, resulting in ~5-μm point-spread function. (f/4 diffraction limit: 1.3 μm)

The optical transport is designed to deliver an "abberation-free" collimated beam to feed multiple diagnostics

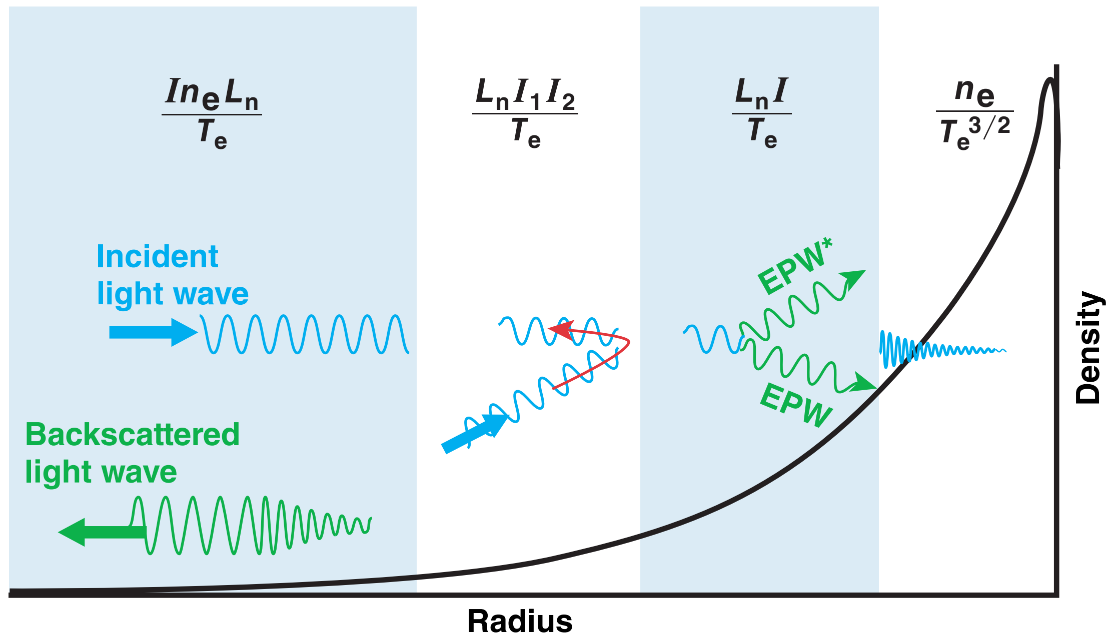


E22830

Outline

The first set of experiments using the 4ω probe laser system were aimed at measuring the plasma density profile in the UV-driven corona

- 4ω diagnostic overview
- Plasma density profile
  - coronal plasma expansion
  - short-pulse channeling
- Laser-generated magnetic fields
- Ongoing work

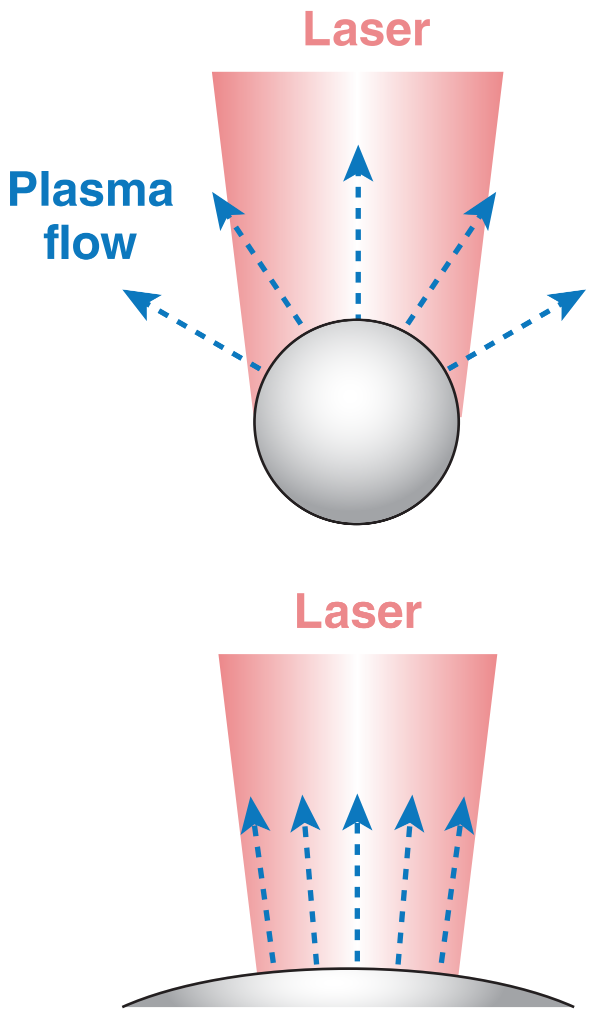


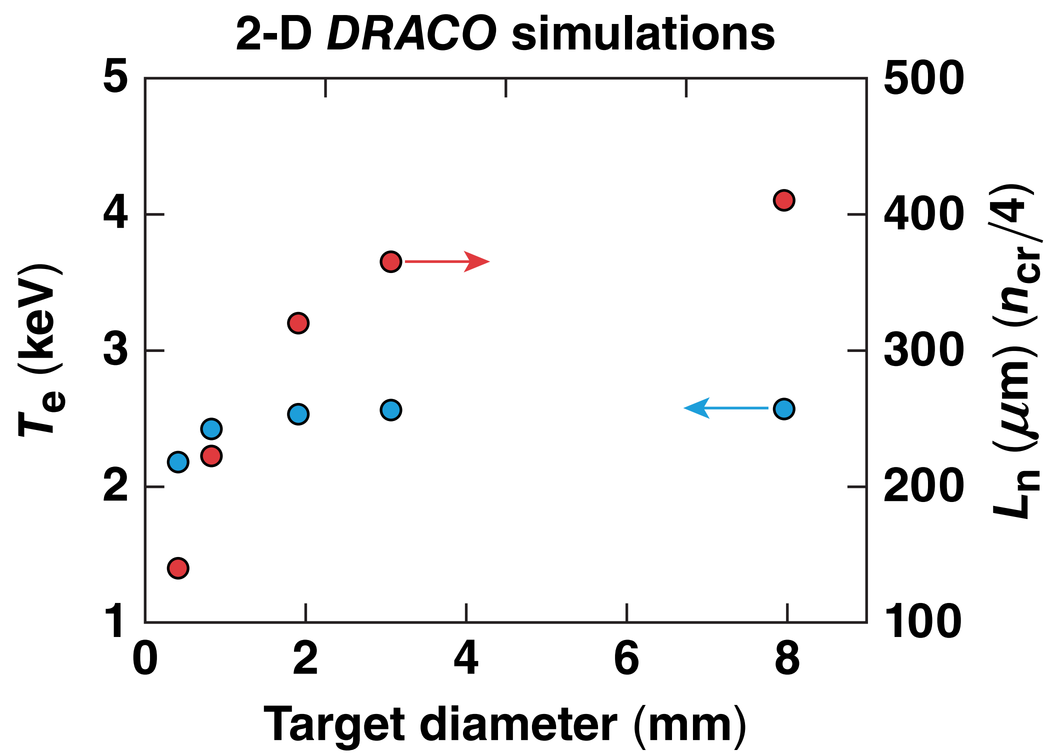
Coronal plasma density measurements are important to accurately predict the laser–plama interaction.

E23055

*Electron plasma wave

Experiments were designed to isolate the dependence of laser–plasma instabilities (LPI's) on the plasma scale length by using targets of varying radii



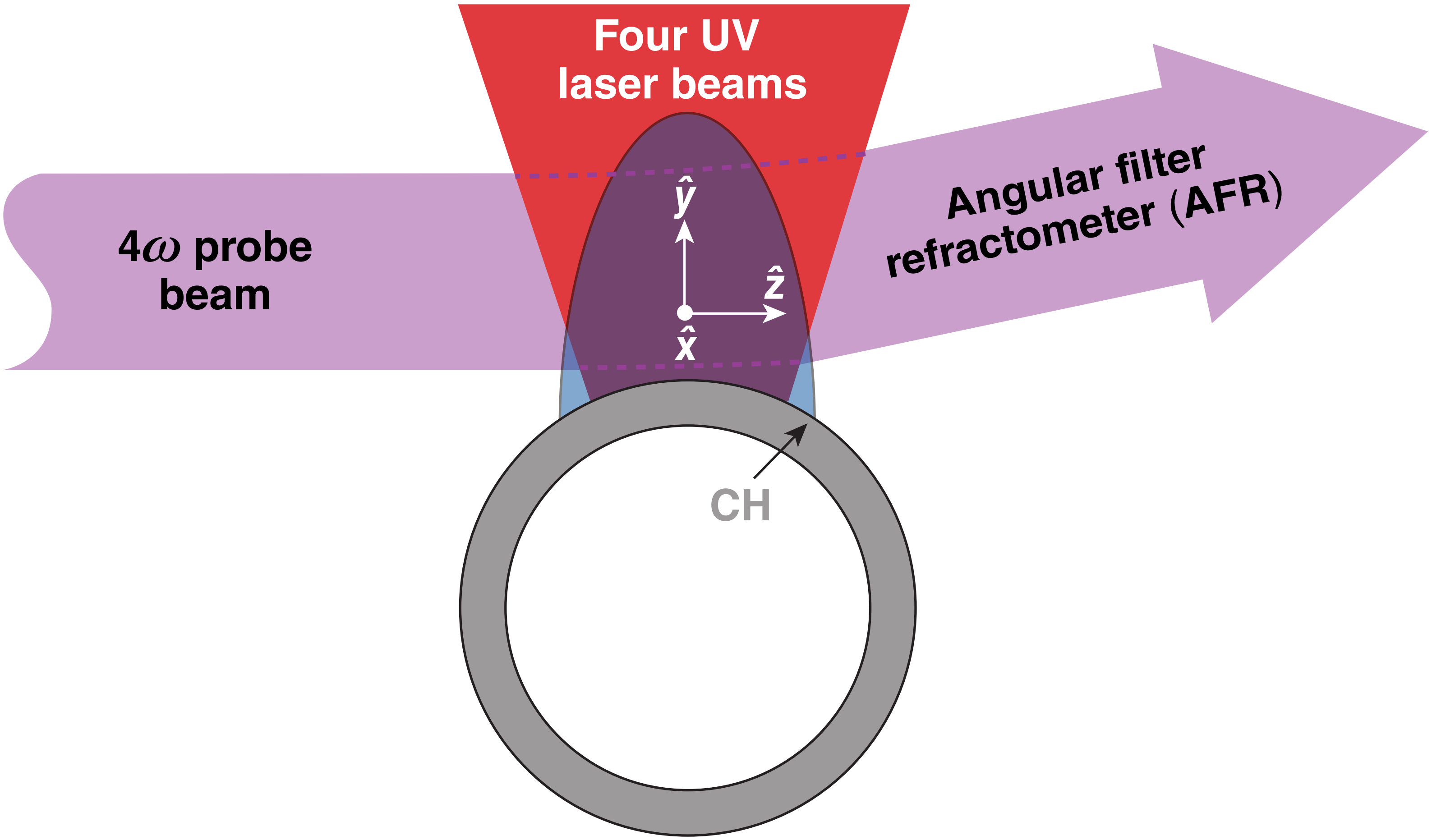


Over the range of experiments, the quarter-critical density scale length was varied by more than a factor of 3.

E22505a

The 4ω probe beam propagates transverse to the laser–plasma interaction (LPI)

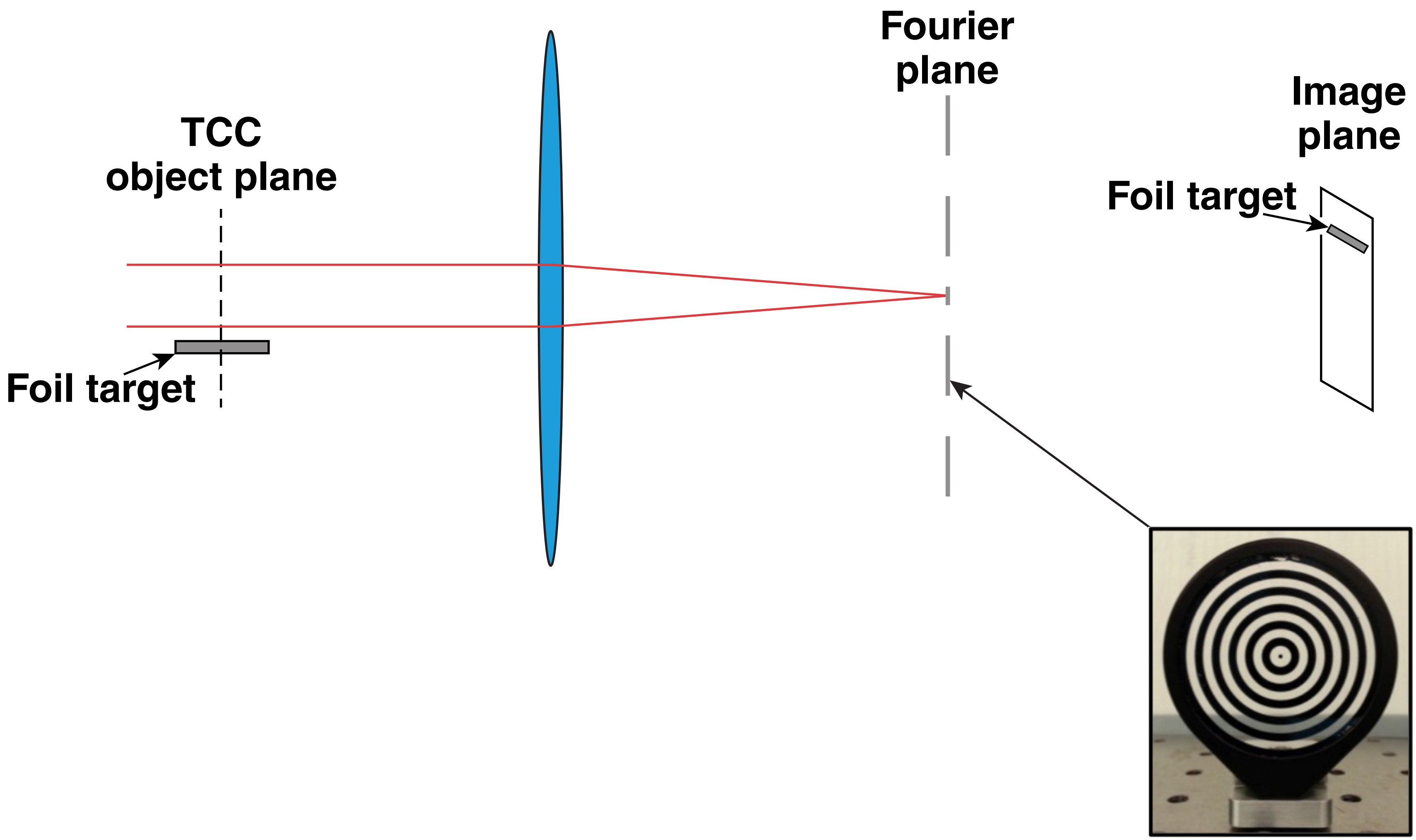
351-nm, 2-ns square, 9-kJ, 1-mm spot (DPP*)



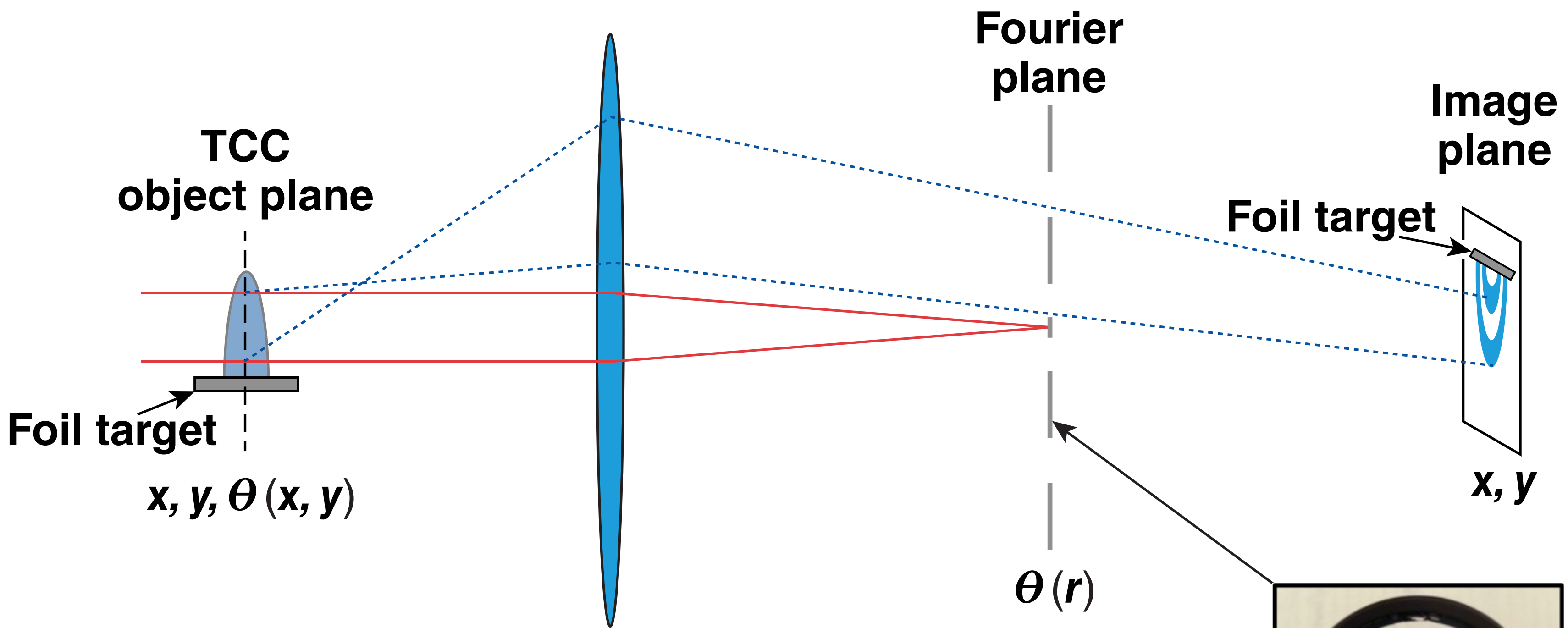
*Distributed phase plate

E22055c

AFR measures the refraction of the probe beam passing through an object at TCC



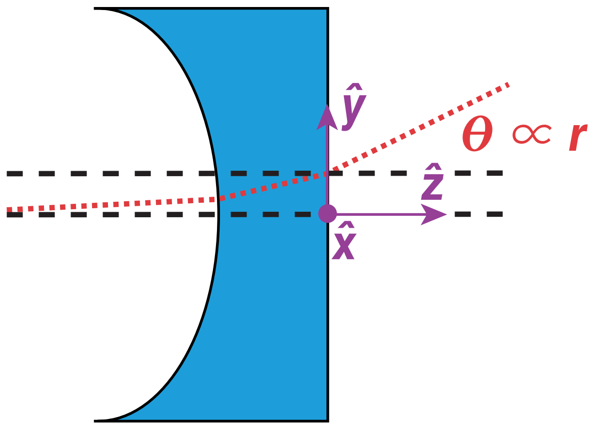
AFR measures the refraction of the probe beam passing through an object at TCC



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

The diagnostic is calibrated using a negative lens that has a well-defined θ (*x*, *y*)

Negative spherical lens at TCC



Round beam shape at Fourier plane

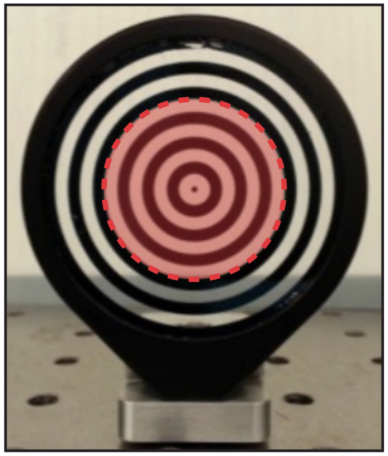
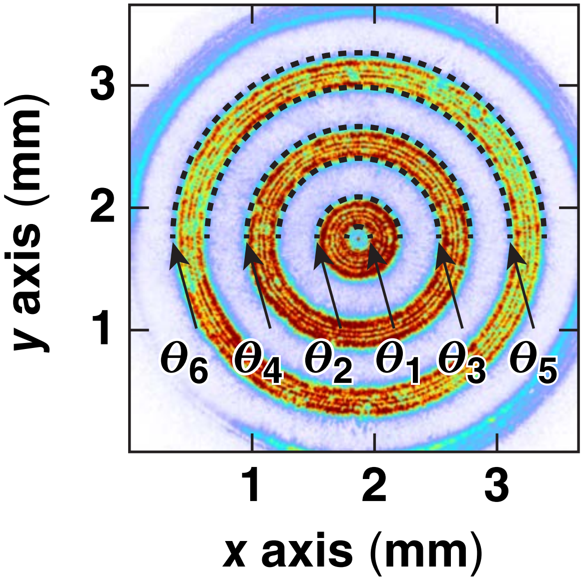


Image using a spherical lens

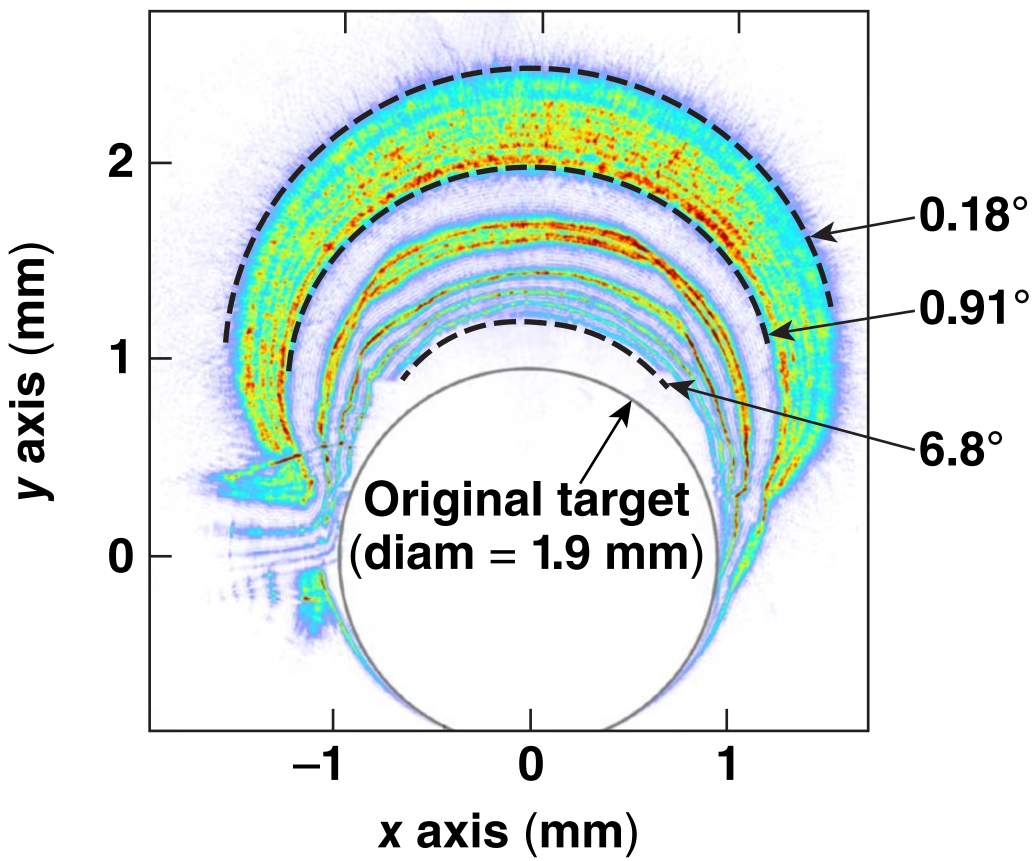


The association of these angles with the specific angular filter bands can be applied to a plasma to measure its refraction profile.

E21941d

The experimental AFR images are analyzed using the calibration angles

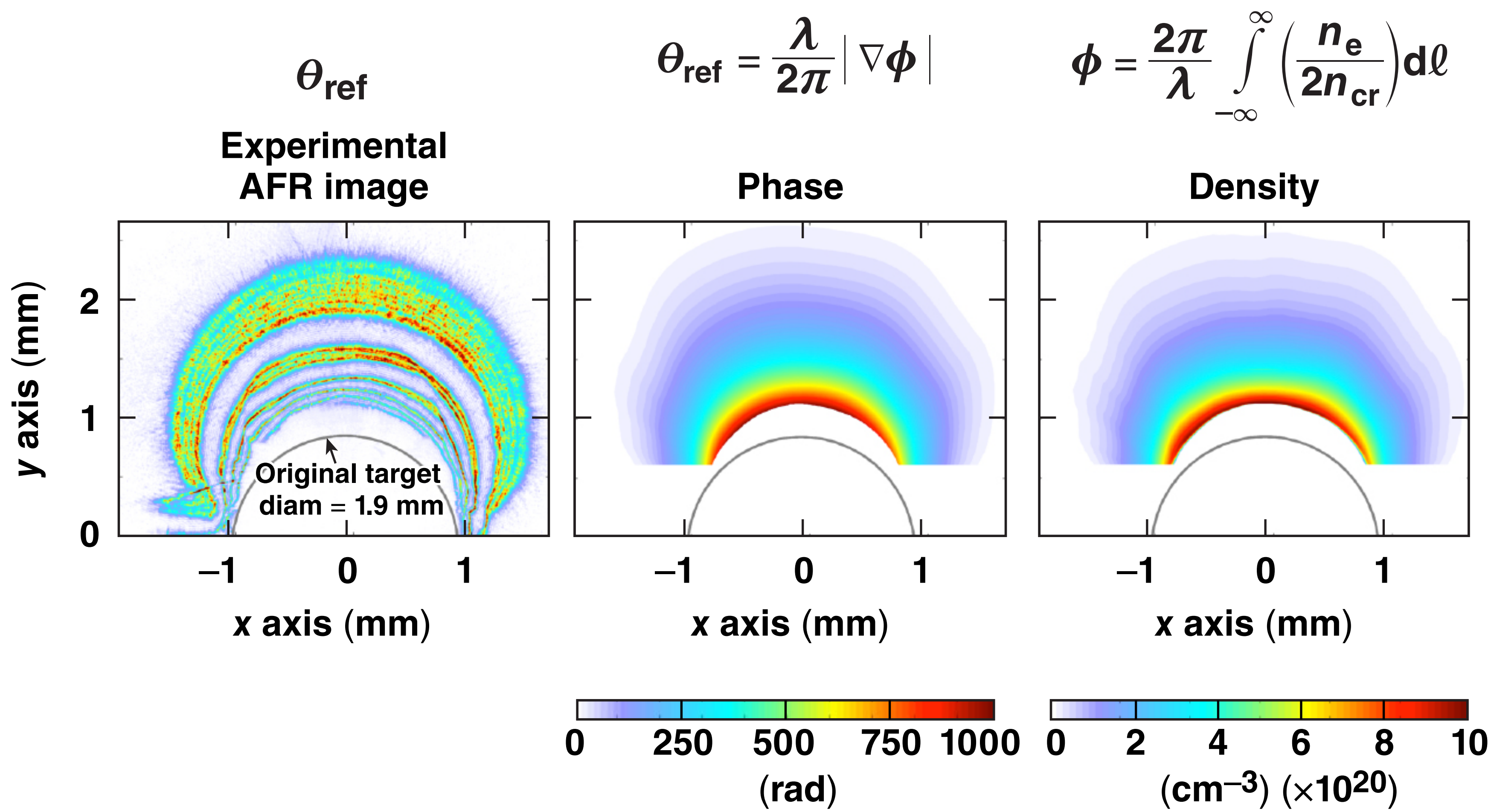
Experimental AFR image



Processing the experimental angular refactometry images creates a contour map of the refraction angle.

E22187b

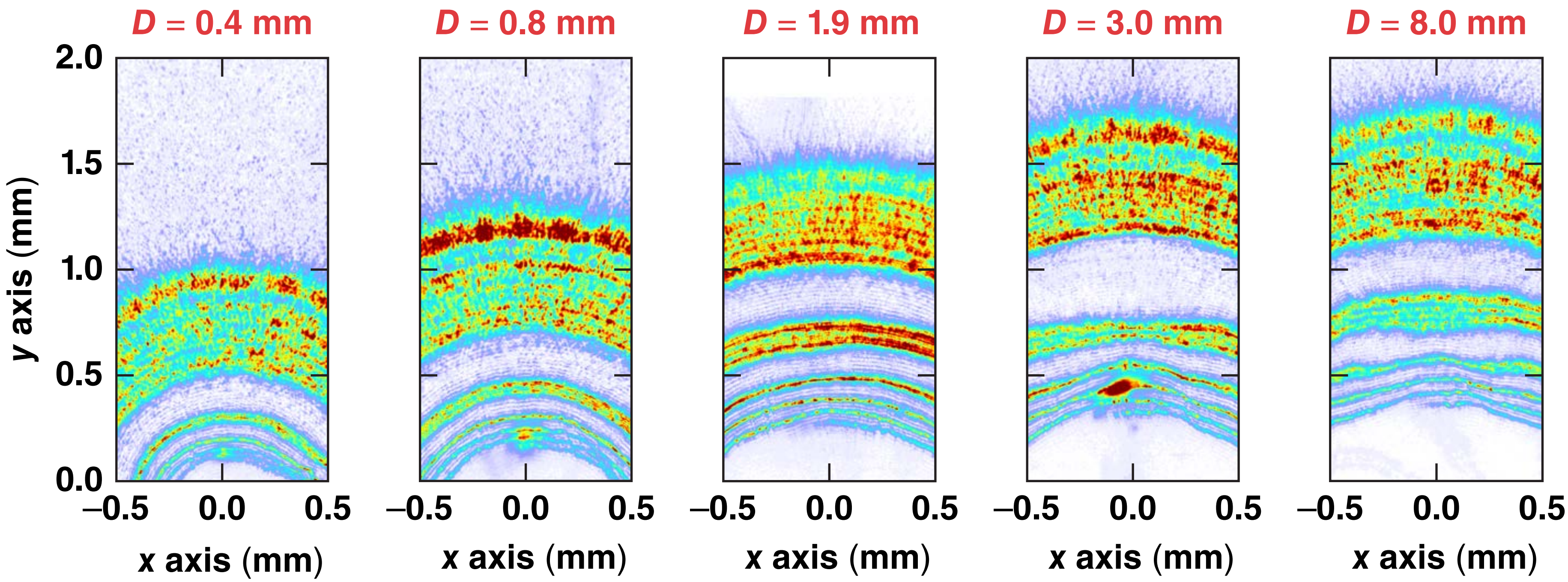
The plasma density profile can be determined from the refractive contour map



E22188b

The plasma expansion from UV-irradiated spheres of varying radii was studied using the AFR diagnostic

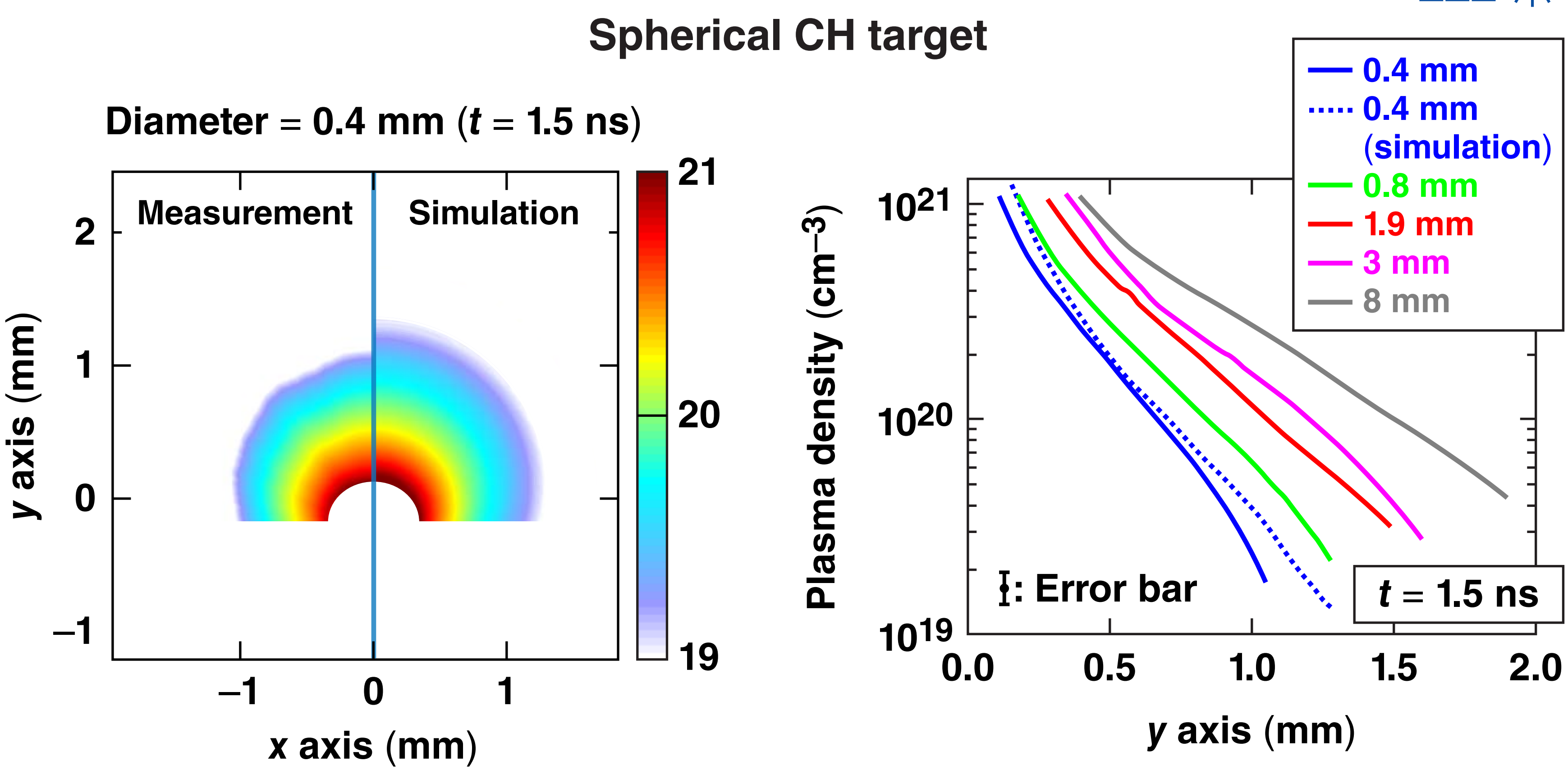
Laser: 2-ns square pulse, probe timing: 1.5 ns



Increasing diameter

E22183c

The measured density profiles were compared to *DRACO* 2-D hydrodynamic simulations run with a flux limiter of 0.06

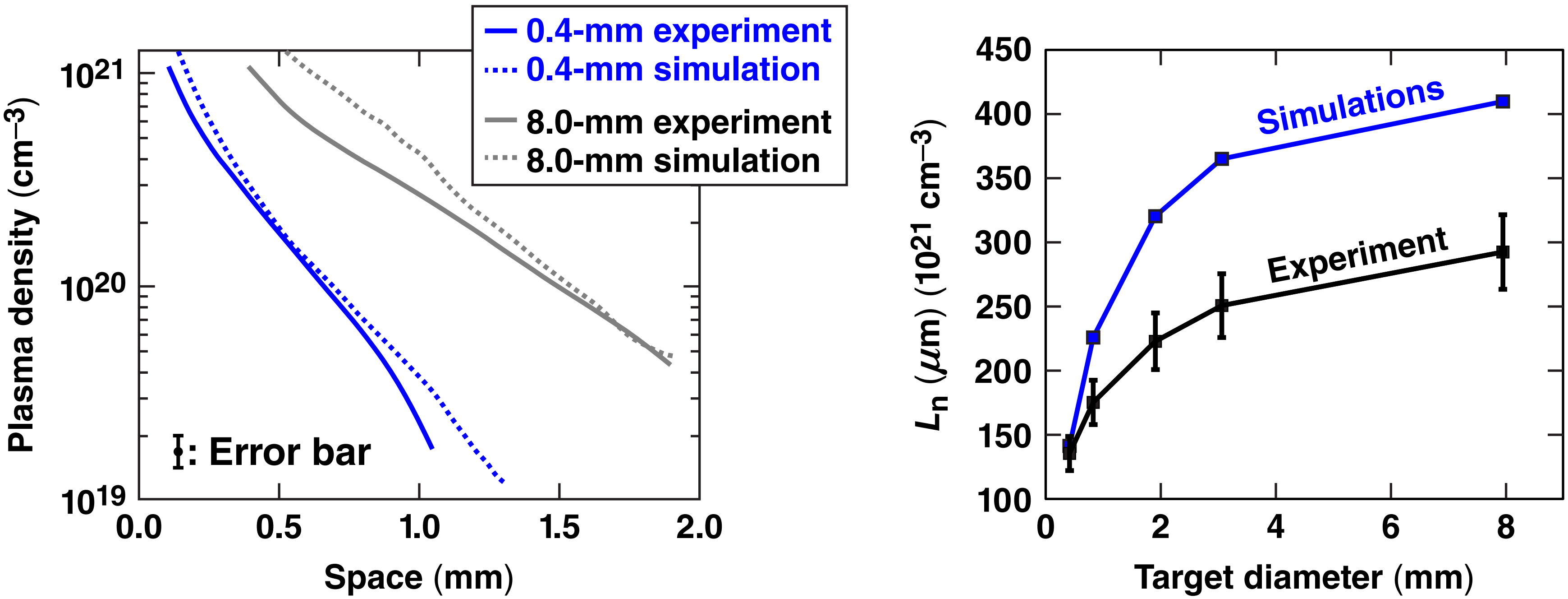


Hydrodynamic simulations are in good agreement with the measurements for small spheres (short scale lengths).

E22571a

As the target diameter is increased, the hydrodynamic simulations predict higher densities and longer scale lengths compared to measurements

Time = 1.5 ns



Three parameter scans link the discrepancy to longer plasma scale lengths

- Shell radius (probe at 1.5 ns)
  - key parameter: scale length
  - result: agreement at small scale lengths, disagreement at large scale lengths
- Probe timing on flat foil
  - key parameter: scale length
  - result: agreement at small scale lengths, disagreement at large scale lengths
- Laser intensity (probe at 1.5 ns)
  - key parameter: laser intensity
  - scale length remains relatively constant
  - result: disagreement across all shots

The results seem to indicate the discrepancy is not LPI driven but an issue in *DRACO* (i.e., lateral heat transport*).

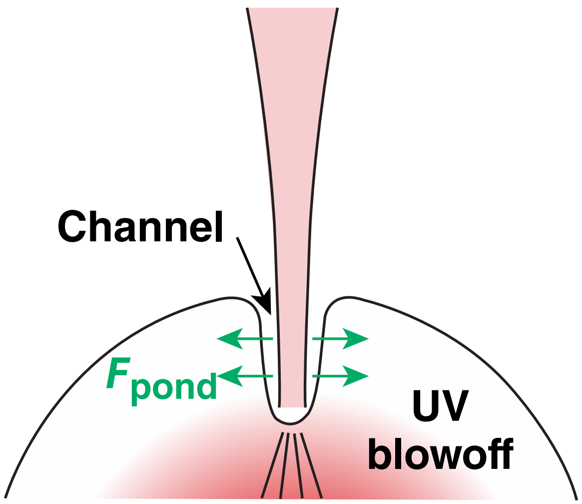
E23054

*D. Ress *et al*., Phys. Fluids B 2, 2448 (1990).

Outline

Imaging of coronal plasma density profiles up to 10^{21} cm^{-3} (n_{cr} for 1 μm) was integral for channeling experiments

- 4ω diagnostic overview
- Plasma density profile
  - coronal plasma expansion
  - short-pulse channeling
- Laser-generated magnetic fields
- Ongoing work



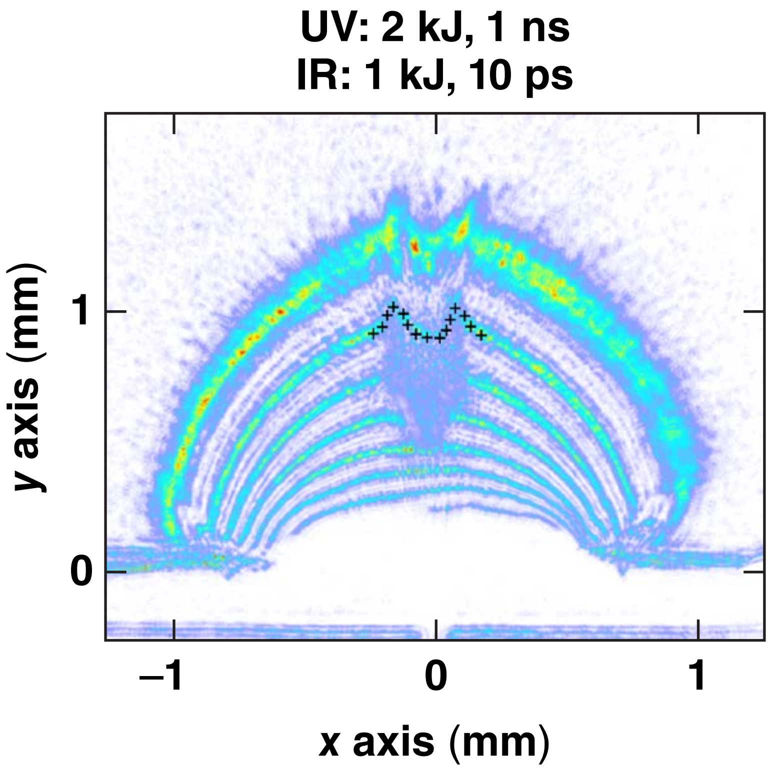
- Guiding of intense laser pulses[1]
- Density profile modification
- High harmonic generation[2]
- Electron transport in HED plasma
- Pumping of x-ray recombination laser[3]
- Laser acceleration of light ions, electrons[4]

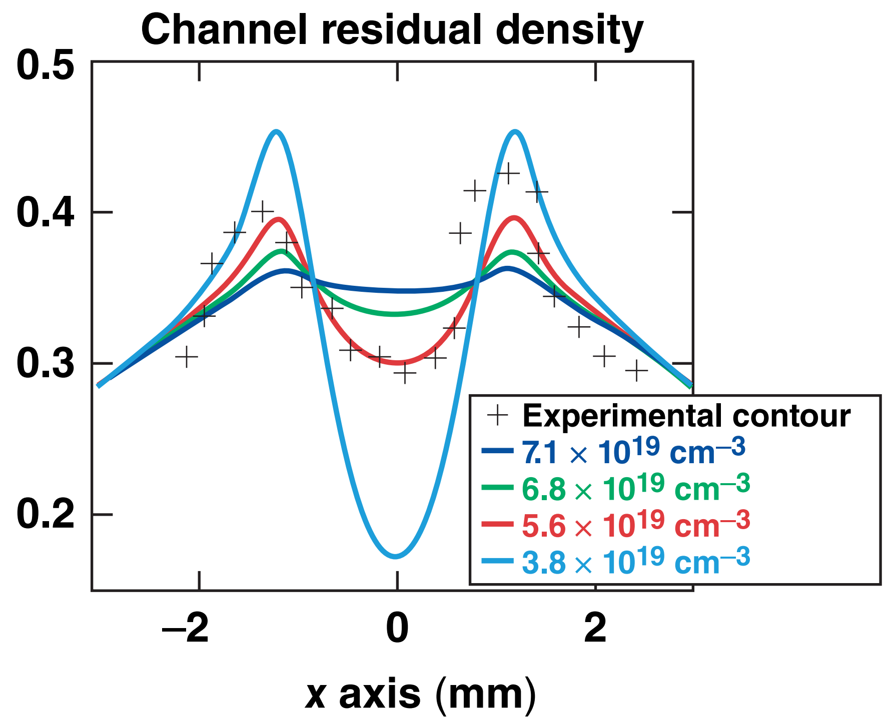
---

[1] C. G. Durfee and H. M. Milchberg, Phys. Rev. Lett. 71, 2409 (1993).
[2] X. F. Li *et al.*, Phys. Rev. A 39, 5751 (1989).
[3] N. H. Burnett and P. B. Corkum, J. Opt. Soc. Am. B 6, 1195 (1989).
[4] T. Tajima and J. M. Dawson, Phys. Rev. Lett. 43, 267 (1979).

E22832

The AFR diagnostic images the channel, offering information on the shape and density modification

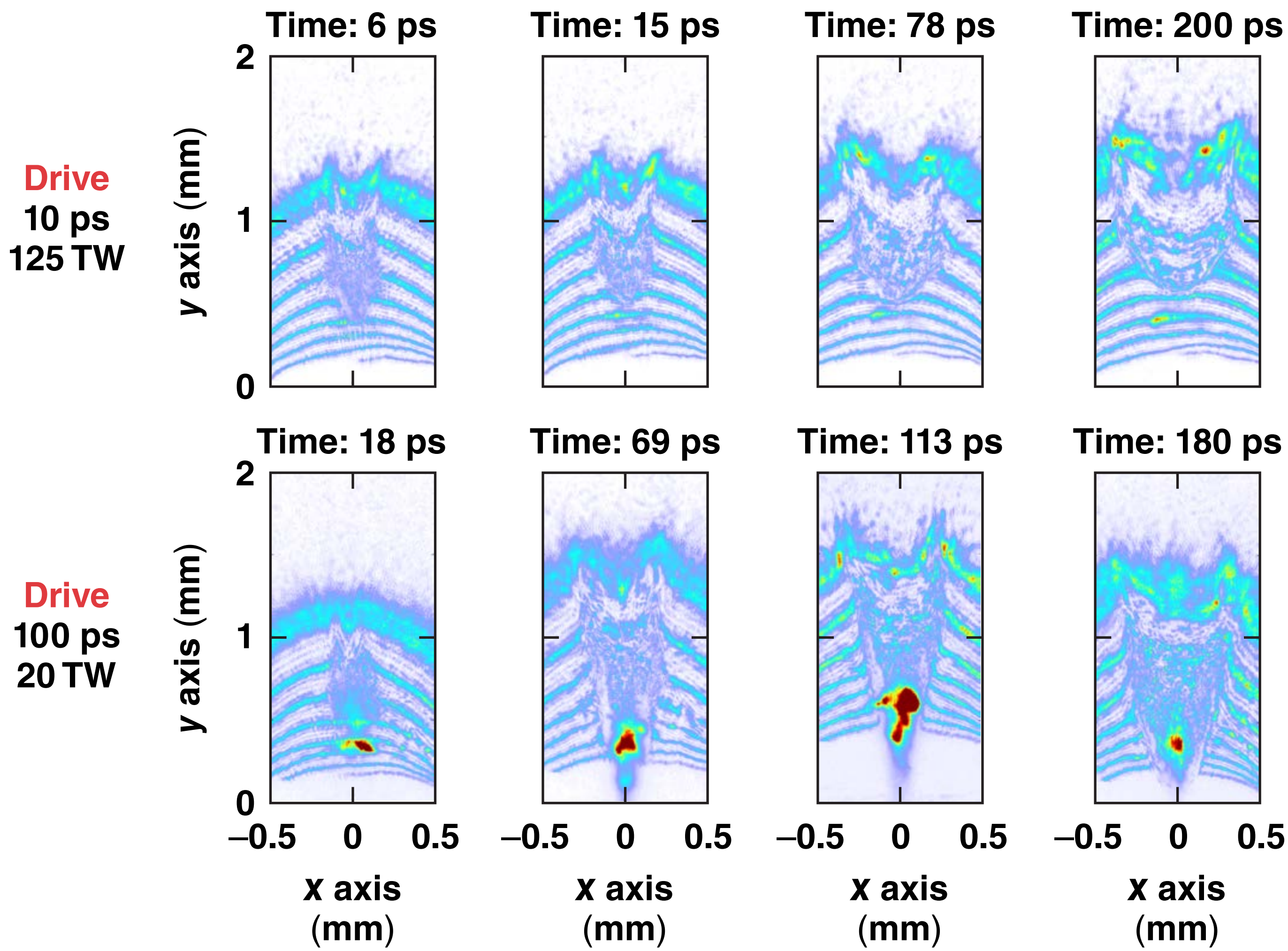




E22833

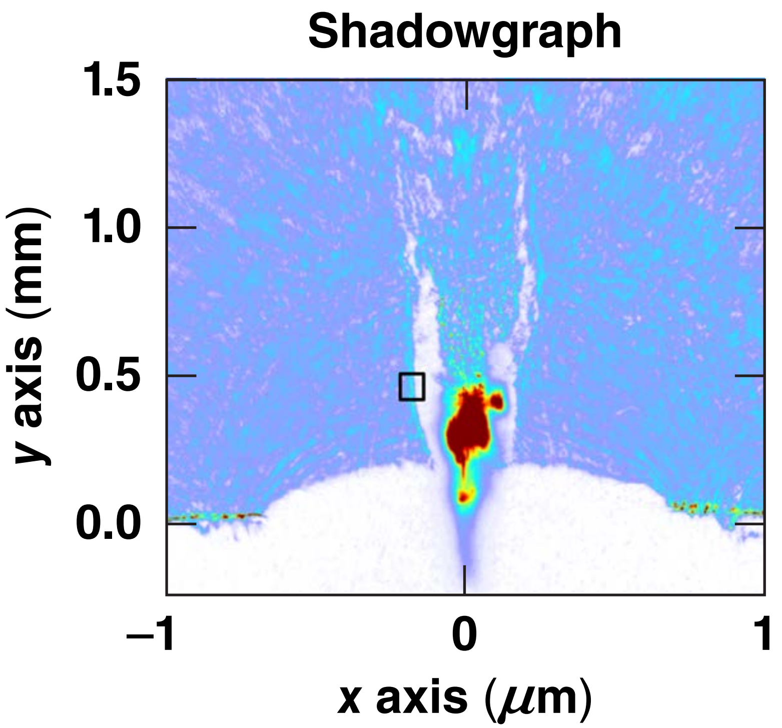
*Courtesy of S. Ivancic

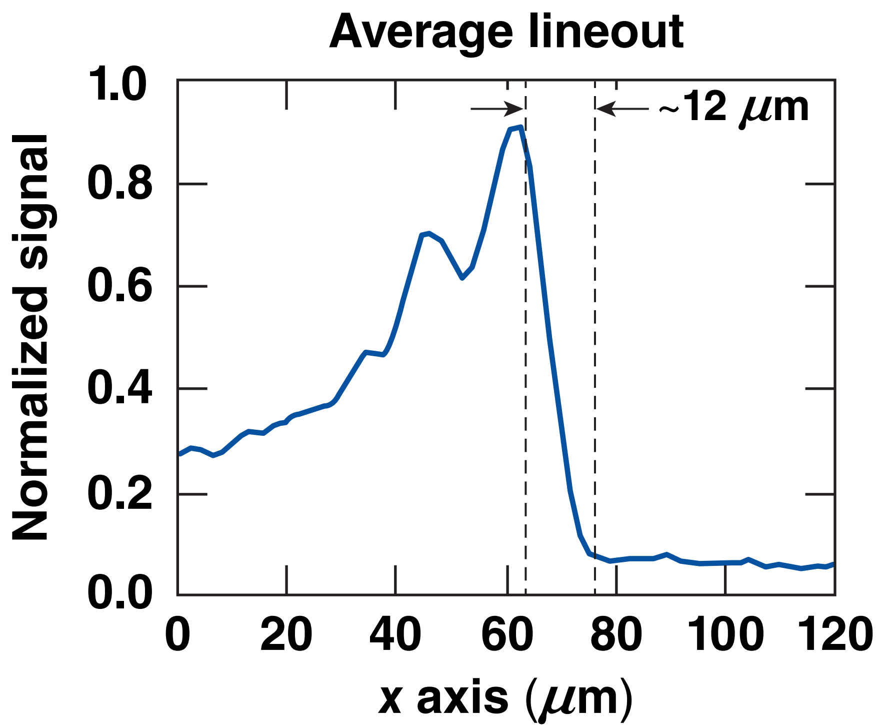
The short duration of the 4ω probe pulse allows for picosecond resolution of the channel dynamics



*Courtesy of S. Ivancic

Shadowgraphy images the channel walls, showing a very sharp rise near the resolution limit of the diagnostic



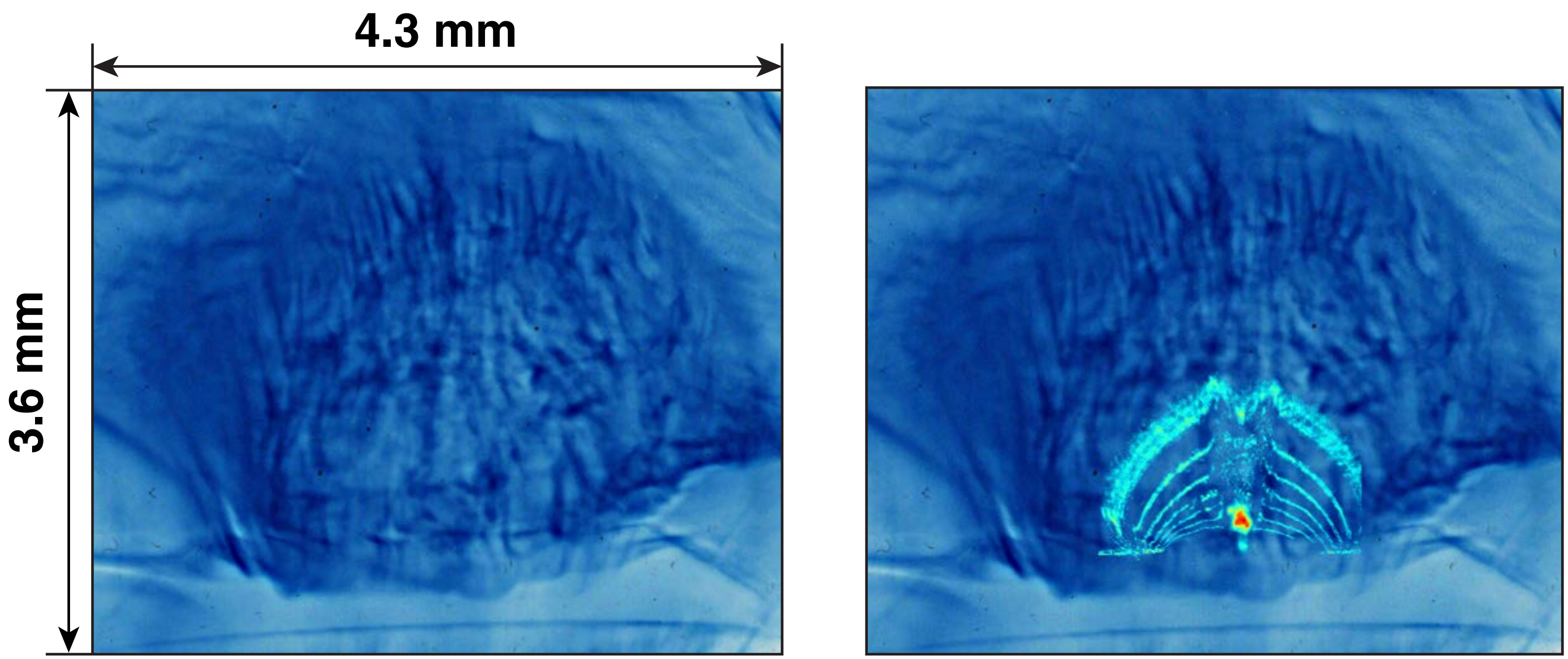


Courtesy of S. Ivancic

E22874

The 4ω probe has enhanced the imaging capabilities on OMEGA EP in underdense plasmas

UV: 1 kJ, 1 ns
IR: 1 kJ, 100 ps



The 4ω probe and proton radiography can be used simultaneously to image electron densities and magnetic/electric fields.

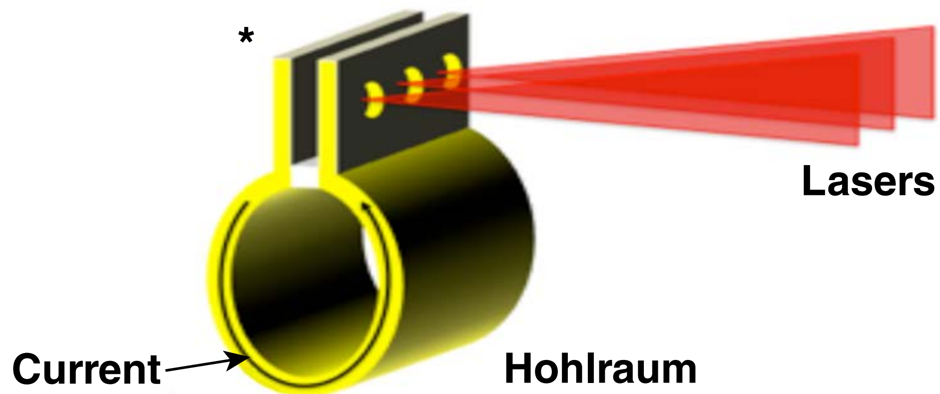
Courtesy of S. Ivancic

Outline

The polarimetry arm of the 4ω diagnostic was activated to measure magnetic fields

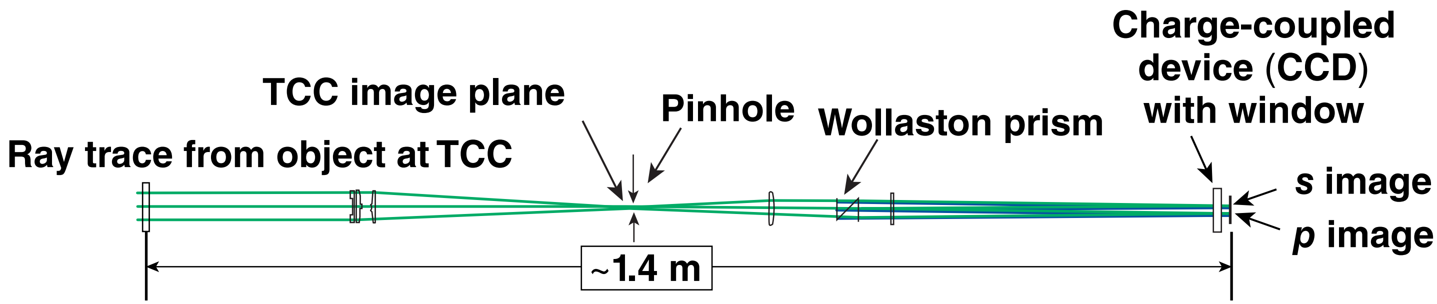
- 4ω diagnostic overview
- Plasma density profile
- Laser-generated magnetic fields
  - magnetized ICF
  - short-pulse–driven magnetic reconnection
- Ongoing work

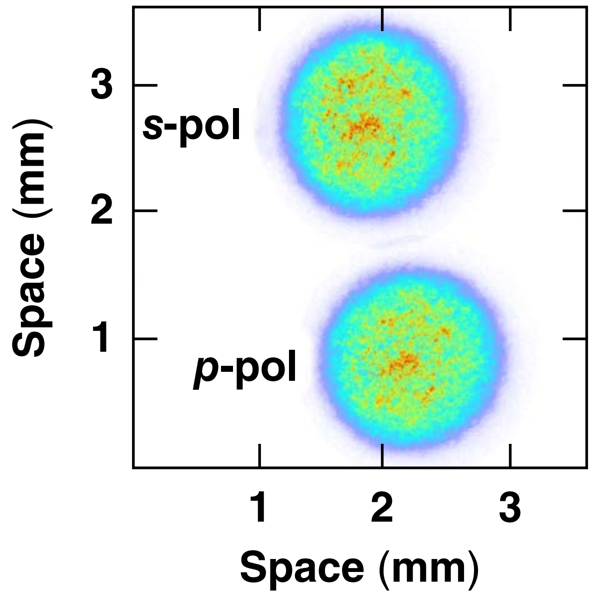
- Magnetized hohlraum to reduce laser–plasma instabilities
  - reduced wall blow-in leads to lower gas pressure
  - reduced thermal transport leads to higher electron temperature

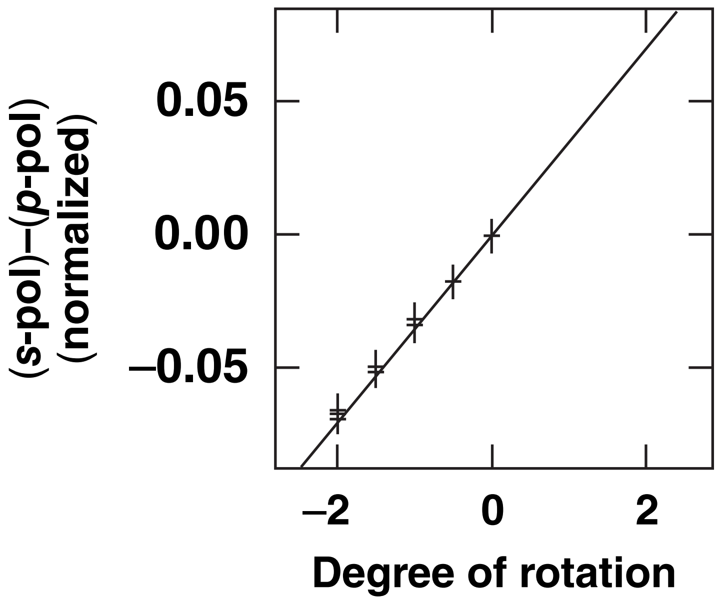


*Courtesy of J. Moody

Magnetic fields are measured by detecting a rotation in the polarization of the 4ω probe beam (Faraday rotation)



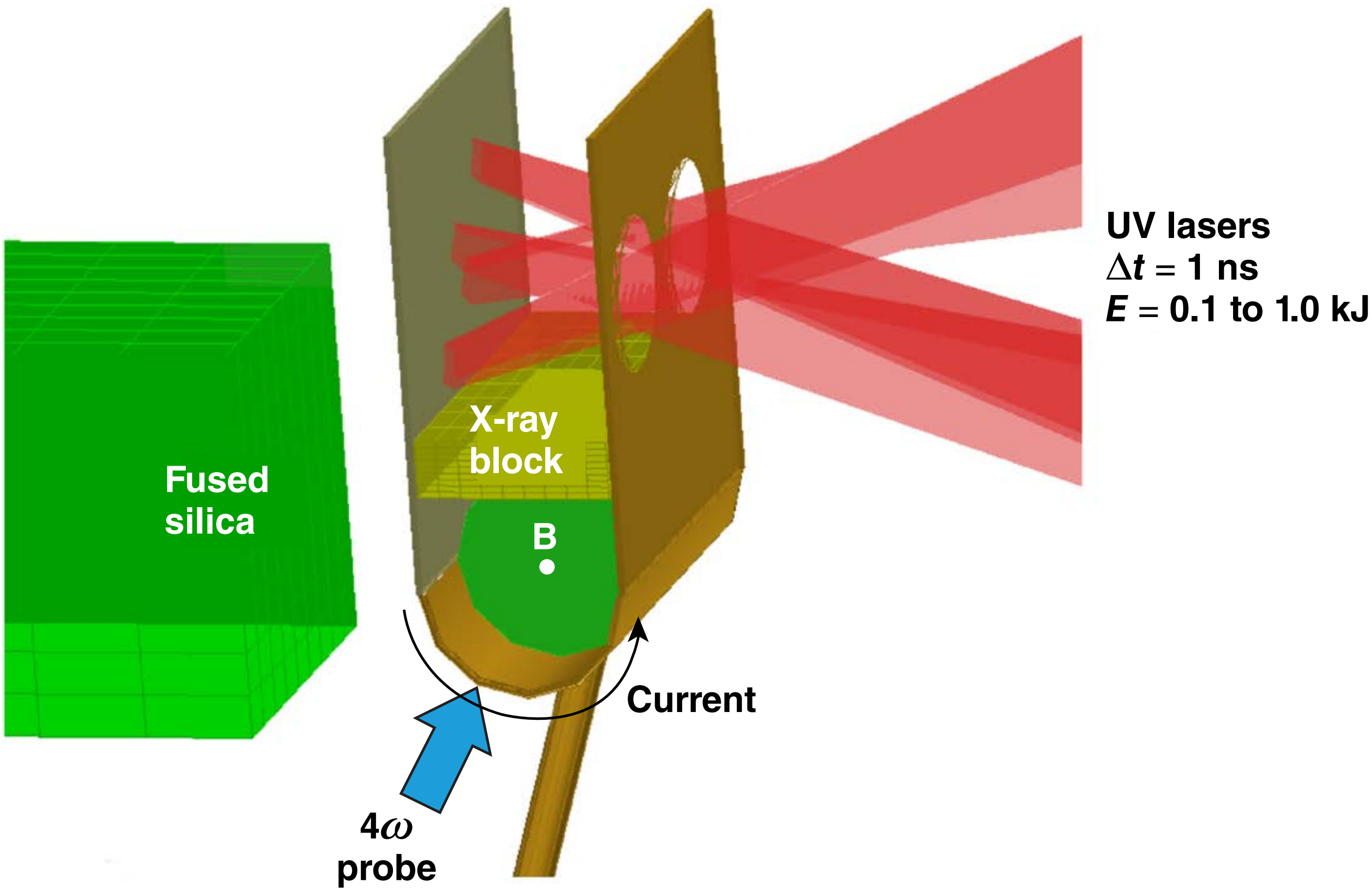




The system can currently measure 0.1° rotations.

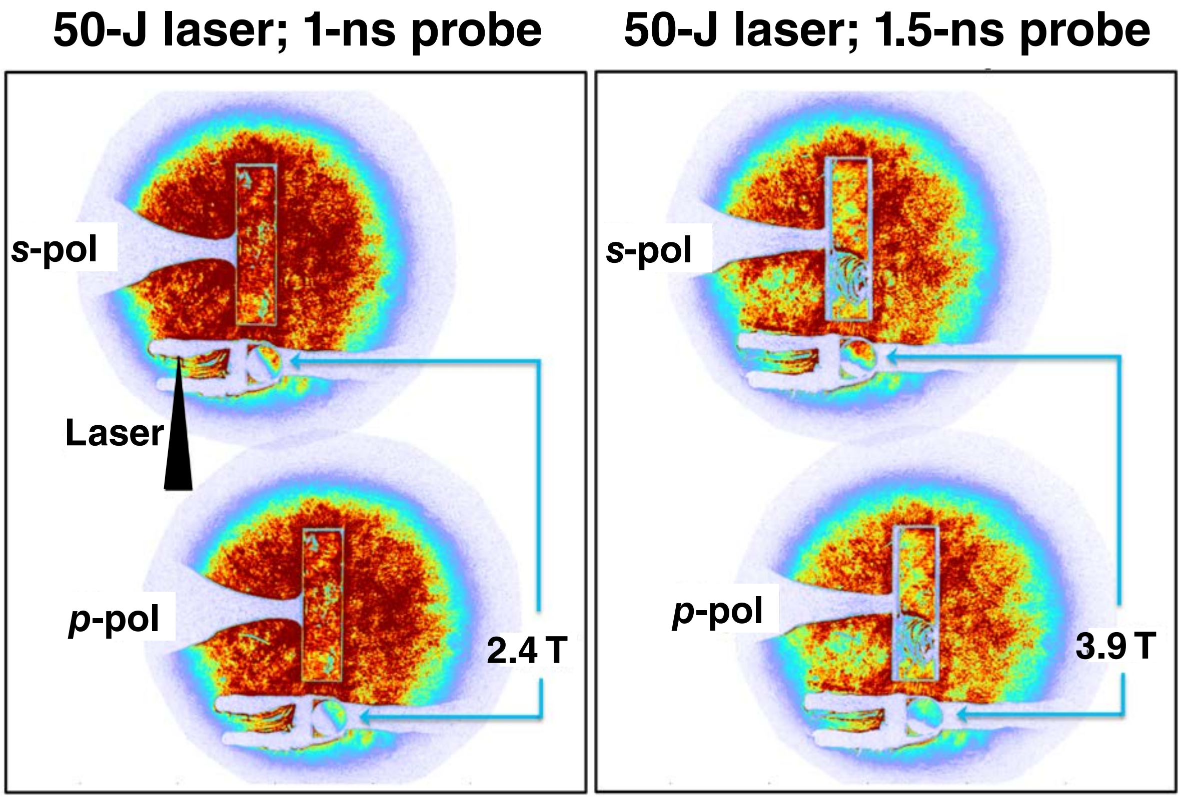
E22837

Experiments were performed to measure magnetic fields generated by a solenoid driven with the OMEGA EP UV laser



E22838

Magnetic fields up to 4 T were measured on the inner piece of glass for a laser energy of 50 J per beam

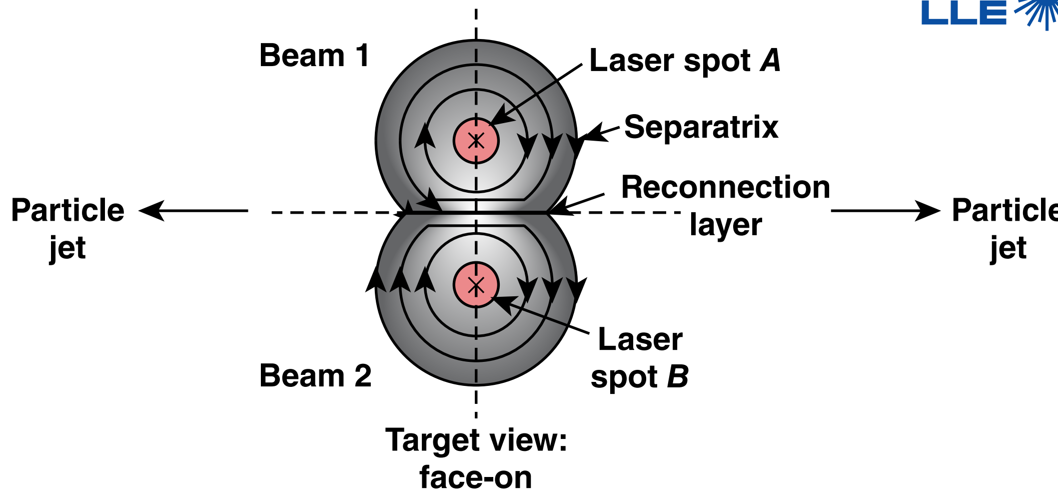


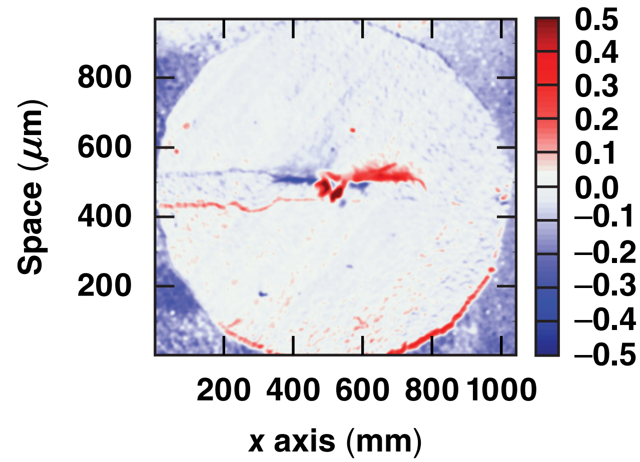
Time scaling at 50 J suggests >100-T fields are produced at 1.5 ns for 500 J.

Courtesy of J. Moody

Collisionless magnetic reconnection as a source of energetic particles is a topic of interest in astrophysics, although the mechanism is unknown

- 4ω diagnostic overview
- Plasma density profile
- Laser-generated magnetic fields
  - magnetized ICF
  - short-pulse–driven magnetic reconnection
- Ongoing work

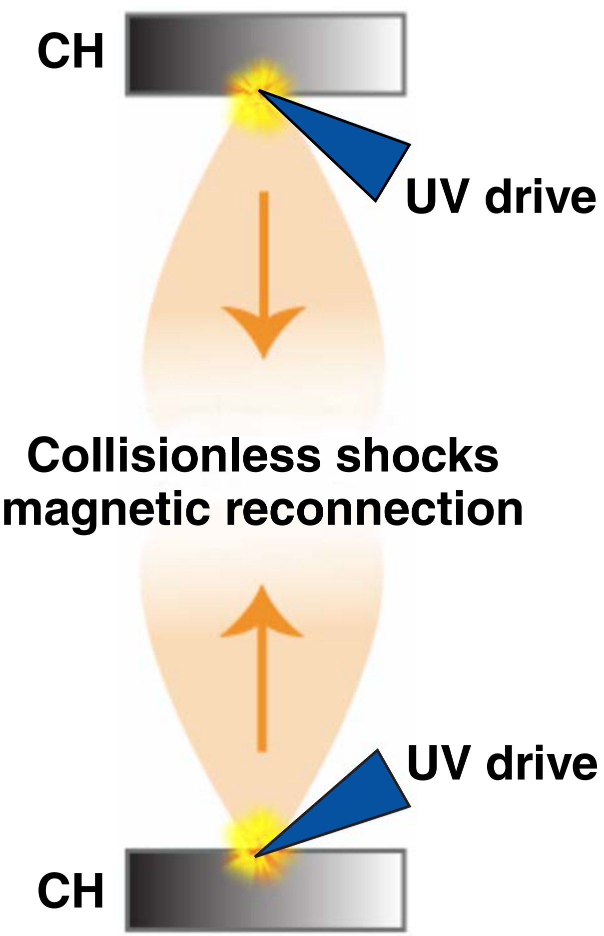




*M. Øieroset *et al.*, Nature 412, 414 (2001).
Courtesy of A. Davies

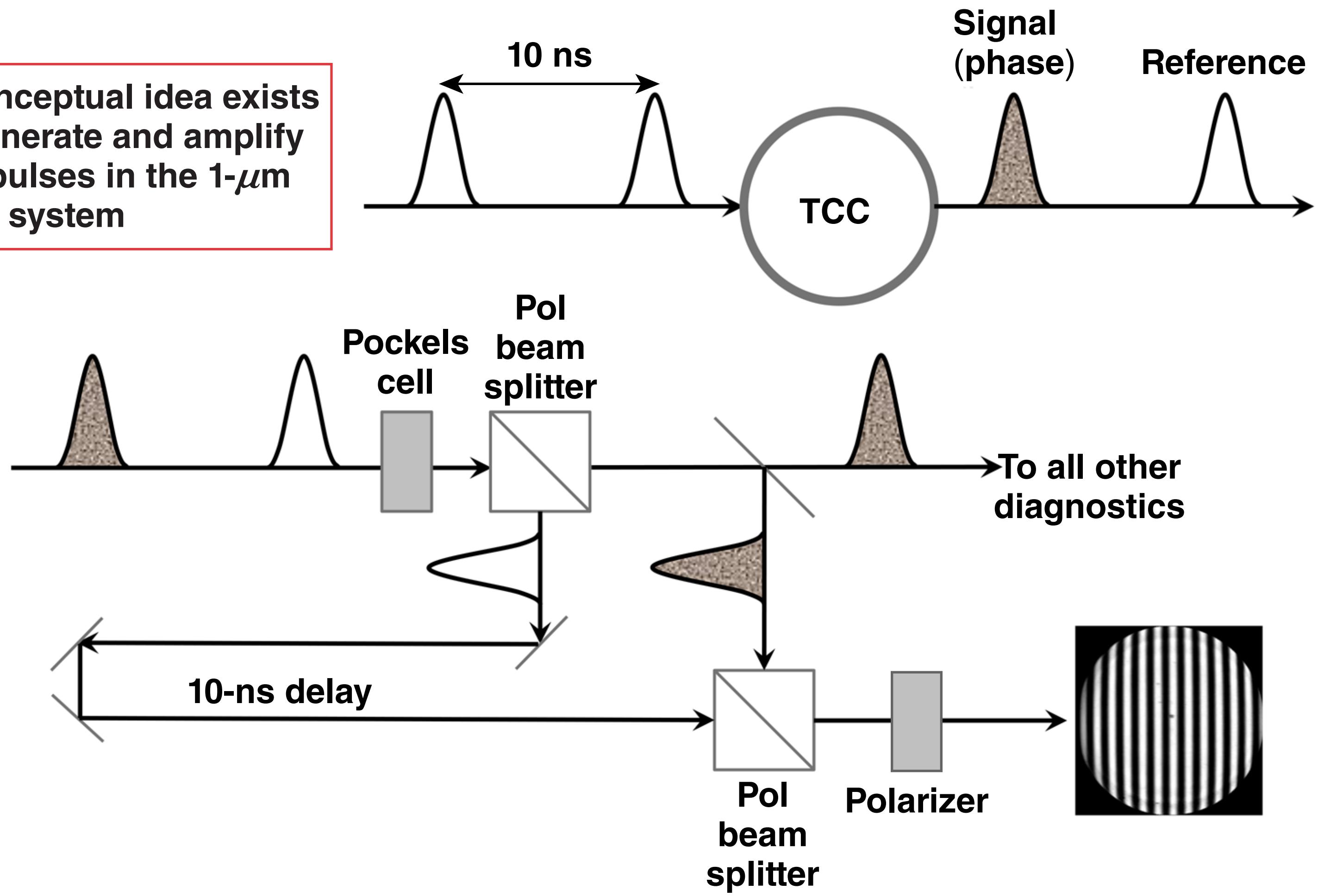
Over 2014 there are 14 shot days (8 external) using the 4ω probe with plans for a new diagnostic, advanced simulation tools, and new experiments

- 4ω diagnostic overview
- Plasma density profile
- Laser-generated magnetic fields
- Ongoing work
  - interferometry for measuring low-density plasmas
  - *MATLAB* analysis package for AFR images
  - new experiment: magnetized liner inertial fusion



A full-aperture interferometer could be built to access low-density plasmas

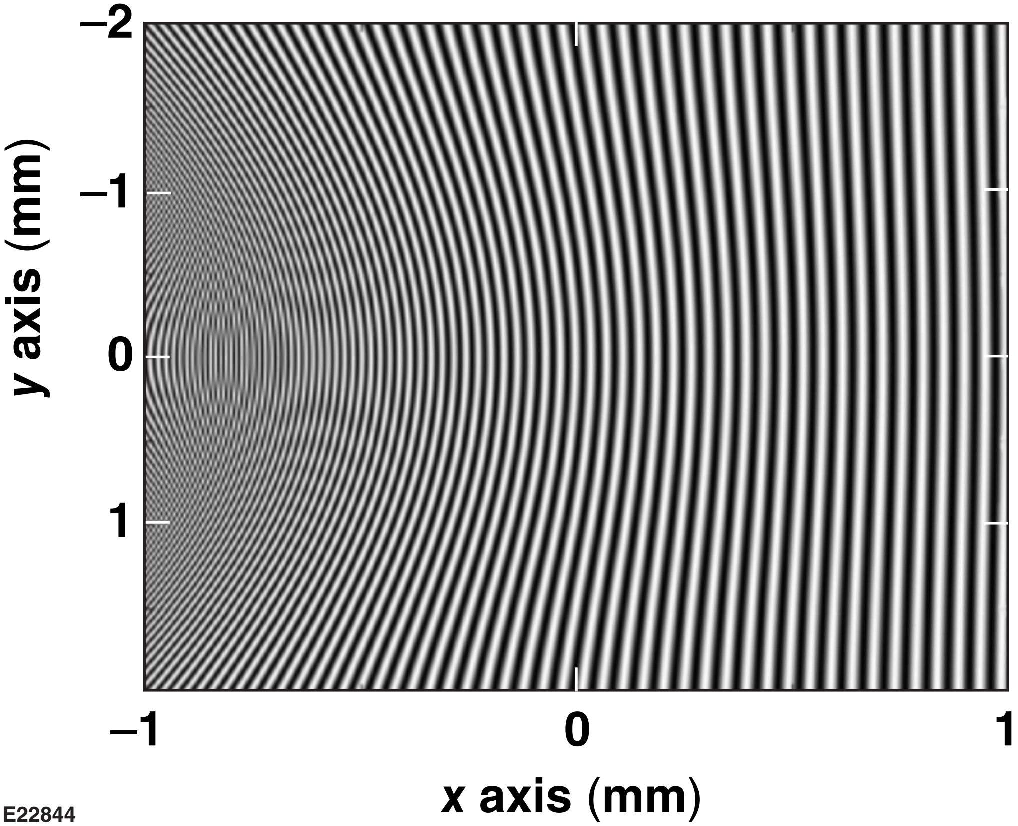
A conceptual idea exists to generate and amplify two pulses in the 1-μm laser system



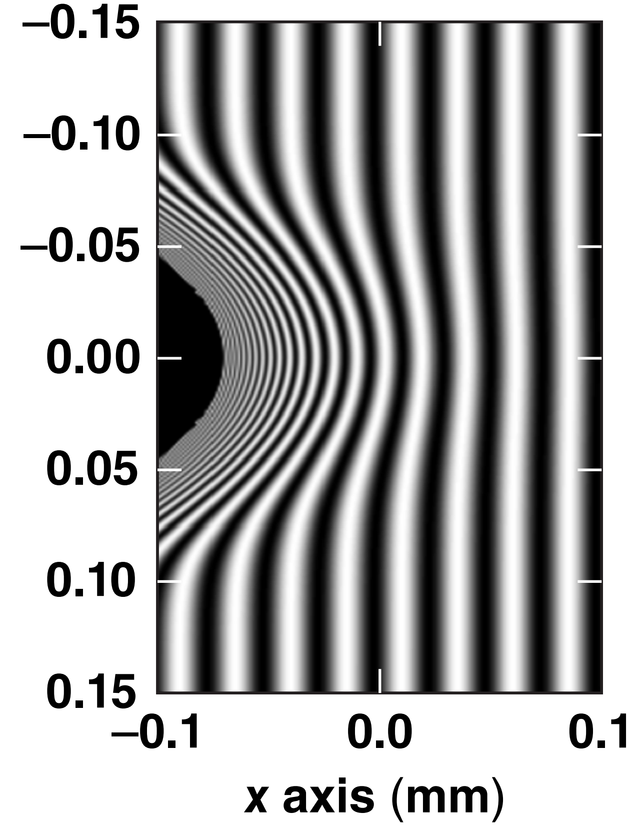
Simulated interferograms generated using model plasma profiles show significant fringe shifts in the plasma area of interest

UR LLE

Colloidal plasmas
$FHWM_y$ = 2.6 mm
$FHWM_z$ = 800 μm
L_x = 400 μm

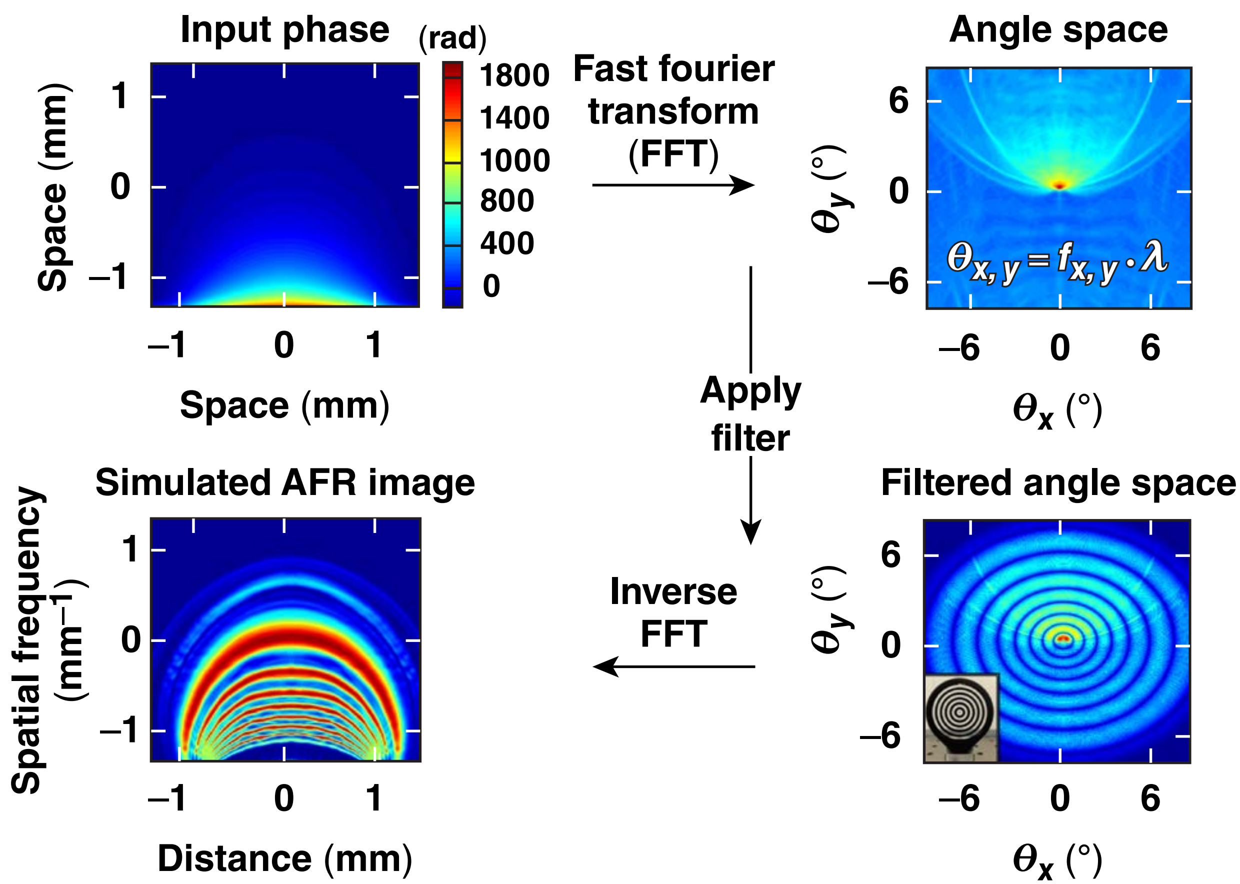


Short-pulse plasmas
$FHWM_y$ = 70 μm
$FHWM_z$ = 70 μm
L_x = 25 μm



E22844

A powerful tool uses Fourier optics to quickly create synthetic AFR images for comparison to experimental images

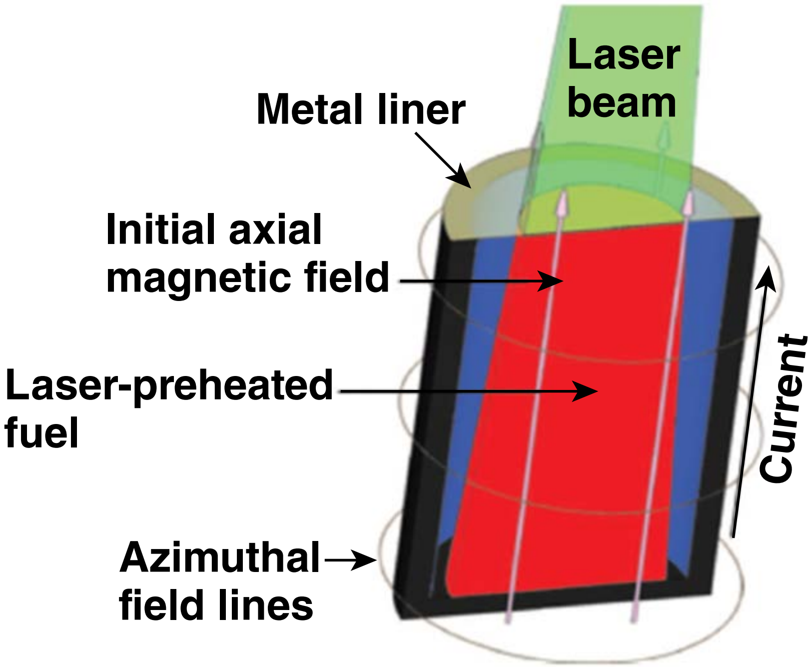


E22845

Courtesy of S. Ivancic

New experiment: Aspects of magnetized liner inertial fusion can be studied on OMEGA EP utilizing the 4ω probe diagnostic

- 5 atm of D_2 gas
- Magneto-inertial fusion electrical discharge system (MIFEDS) to provide axial magnetic field
- AFR to measure plasma density and extent
- Shadowgraphy to show fine-scale laser filamentation



- How does a high-energy laser deposit energy in an underdense D_2 gas?
- How does magnetization affect the dynamics?

E22846

Summary/Conclusions

The fourth-harmonic (263-nm) probe diagnostic system provides an opportunity to study the plasma conditions for a variety of high-energy-density (HED) and basic physics studies

UR LLE

- The 4ω diagnostic system was activated near the beginning of 2013 on the OMEGA EP Laser System
- A novel diagnostic, angular filter refractometry (AFR), was developed to study plasma density profiles up to 10^{21} cm^{-3} (UV-irradiated targets and short-pulse channeling)
- Polarimetry has been recently activated to measure laser-generated magnetic fields (magnetized ICF and short-pulse magnetic reconnection)
- Interferometry is at the conceptual stage to extend the low end of the measurement range for plasma density profiles

Interferometry of long-scale-length plasmas
L_n = 400 μm ; FHWM = 1 mm