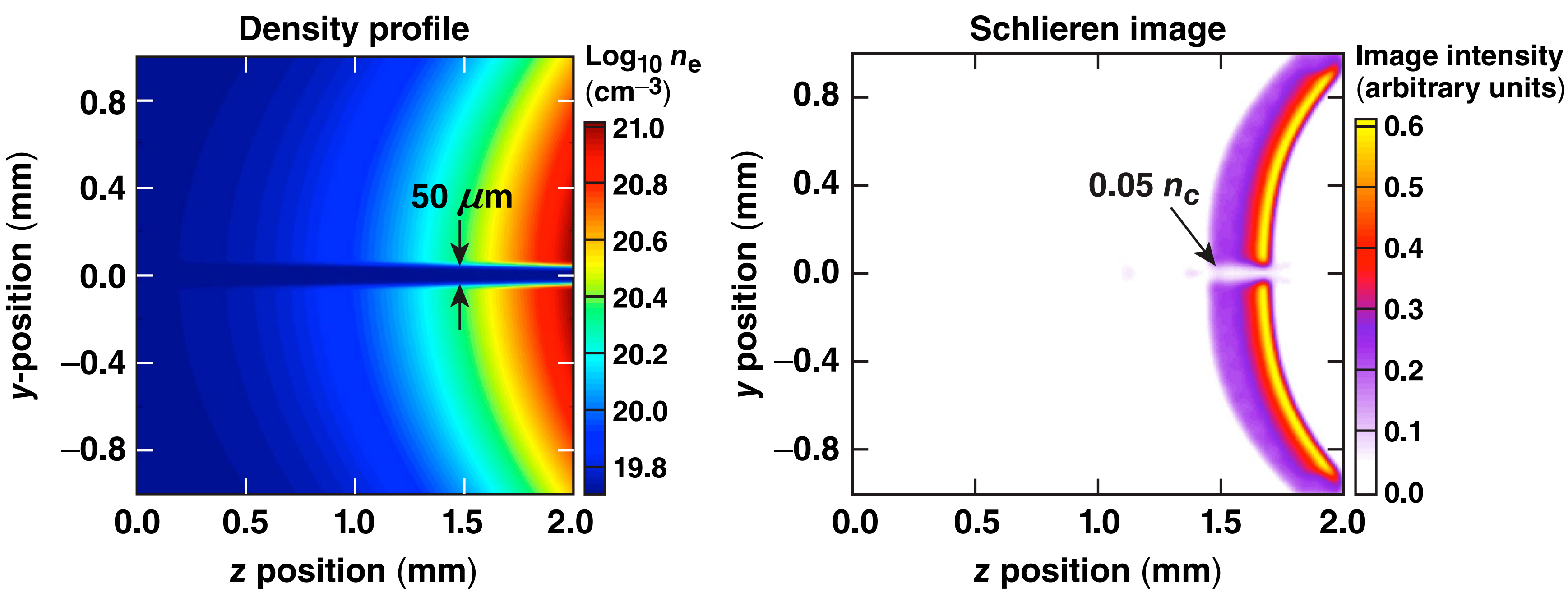
Ray-Trace Simulations for the Optical 4ω Probe Diagnostic on OMEGA EP



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Summary

Ray-trace Simulations of the 4ω probe diagnostic were performed with long-scale–length plasmas that are relevant to fast-ignition channeling experiments

- A 50-μm-wide channel in long-scale–length plasma is clearly resolved by Schlieren and shadowgraphy imaging with the 4ω probe system
- Quantitative shadowgraphy images can be used to find the scale length in a simulated exponentially-stratified plasma
- Modulations in the probe beam can limit the accuracy of the shadowgraph analysis when the wavelength is comparable to the density scale length

Collaborators

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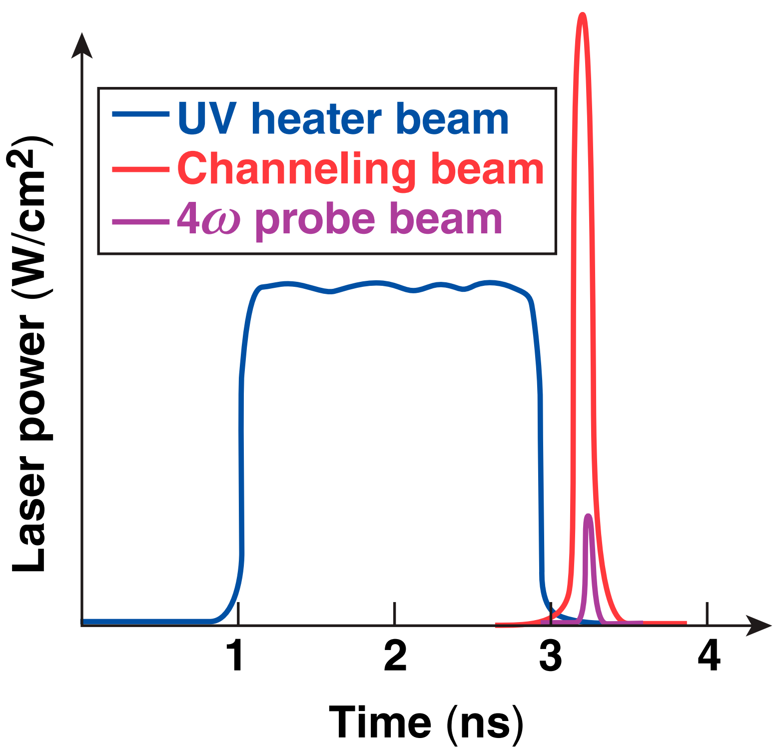
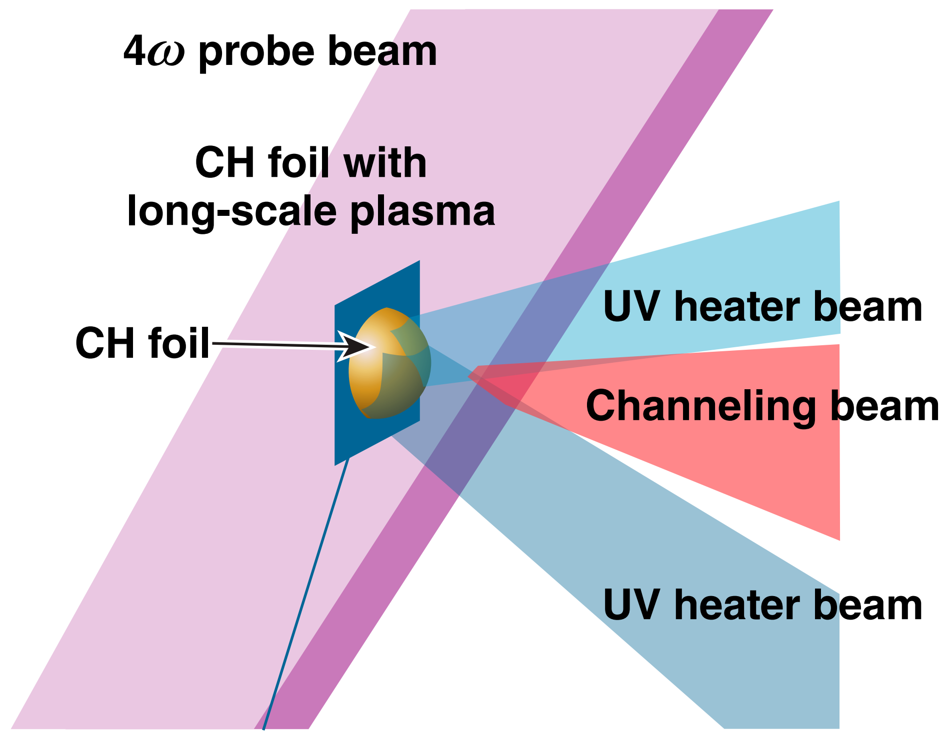
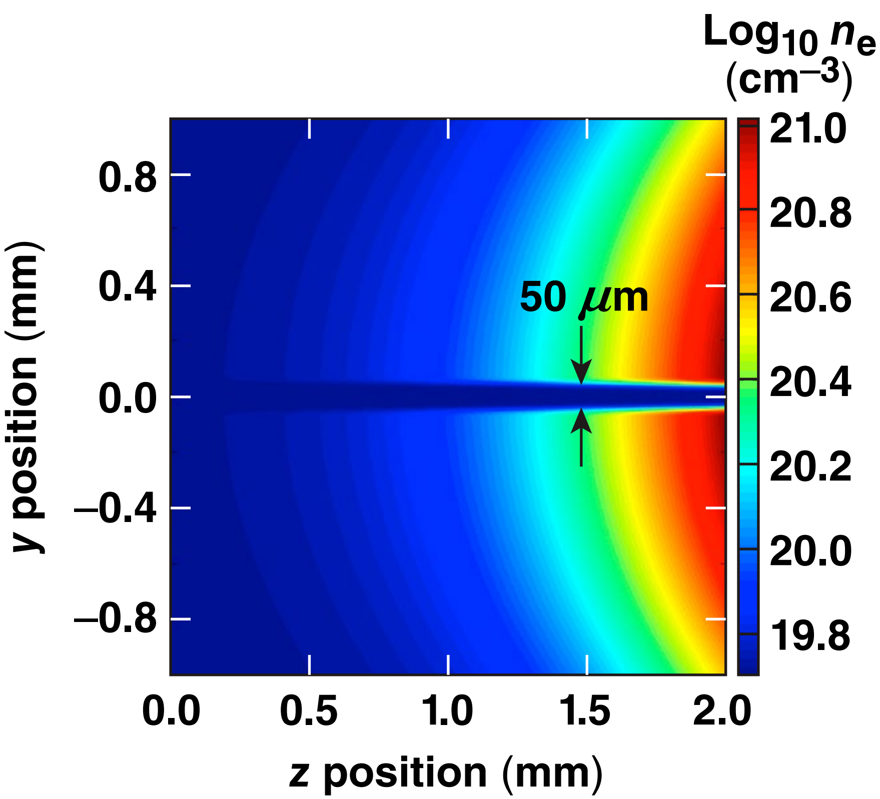
The optical probe on OMEGA EP will diagnose plasmas with density scale lengths relevant to channeling





- Direct measurement of density scale length $\{L_s = [\nabla(n_e)/n_e]^{-1}\}$ from the deflection of the optical probe
- Large spatial field of view is available (5 mm × 5 mm)
- Channels, cavitation, and other structures inside the plasma can be imaged by an optical probe

A typical plasma that can be generated with OMEGA EP was simulated as an optical element in a ray-trace code



Density profile

$$n_e(r,z) = n_p e^{\frac{z}{L}} e^{-r^2/\sigma^2}$$

Refractive index

$$\mu(r,z) = \sqrt{1 - \frac{n_e(r,z)}{n_c}}$$

Peak density, n_p	10^{21} cm^{-3}
Scale length, L_s	300 μm
Radial extent, σ	800 μm
Critical density of optical probe, n_c	1.6×10^{22} cm^{-3}
Channel	50-μm wide with density depressed to 0.05 n_p

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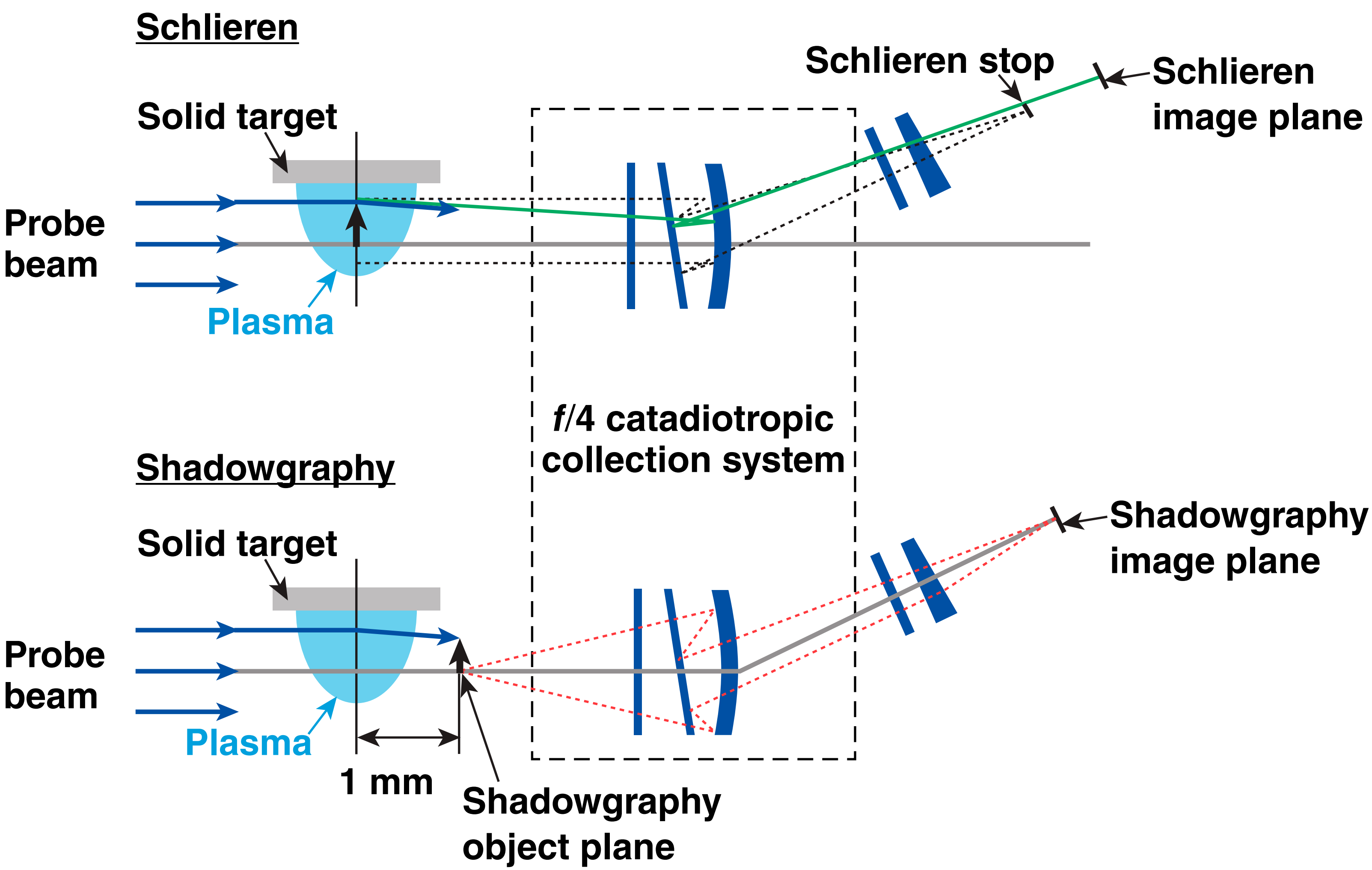
The fourth-harmonic probe optical system* will be used to make Schlieren and shadowgraphy images



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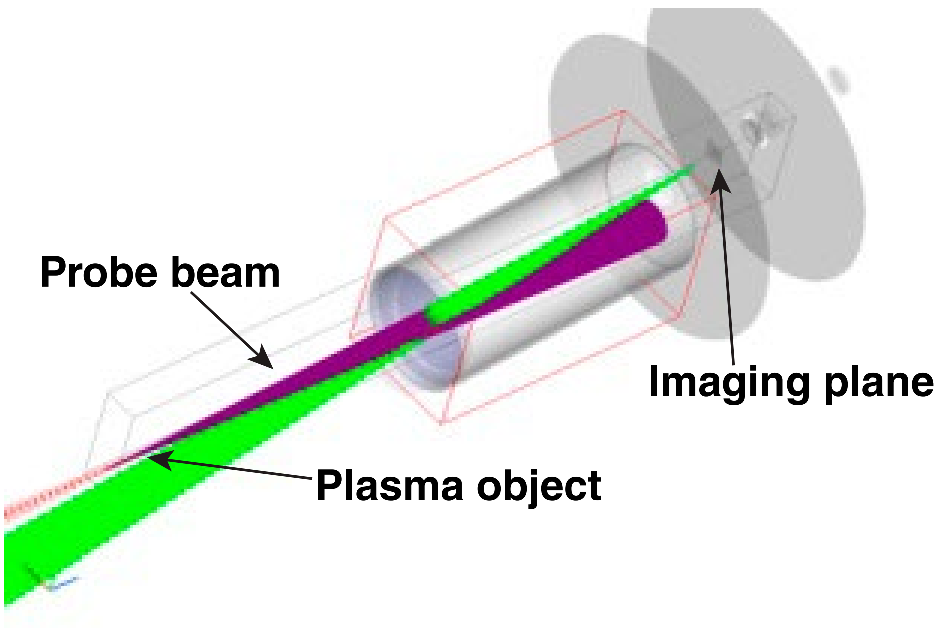
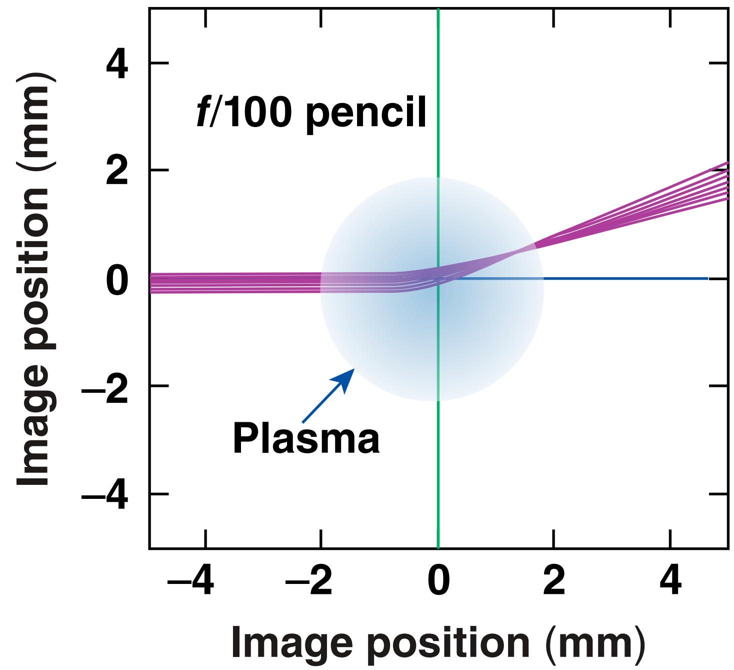
*D. H. Froula *et al*. Rev. Sci. Instrum. 83, 10E523 (2012).

The ray trace is calculated by the ray-trace code *FRED** with a script generated refractive index





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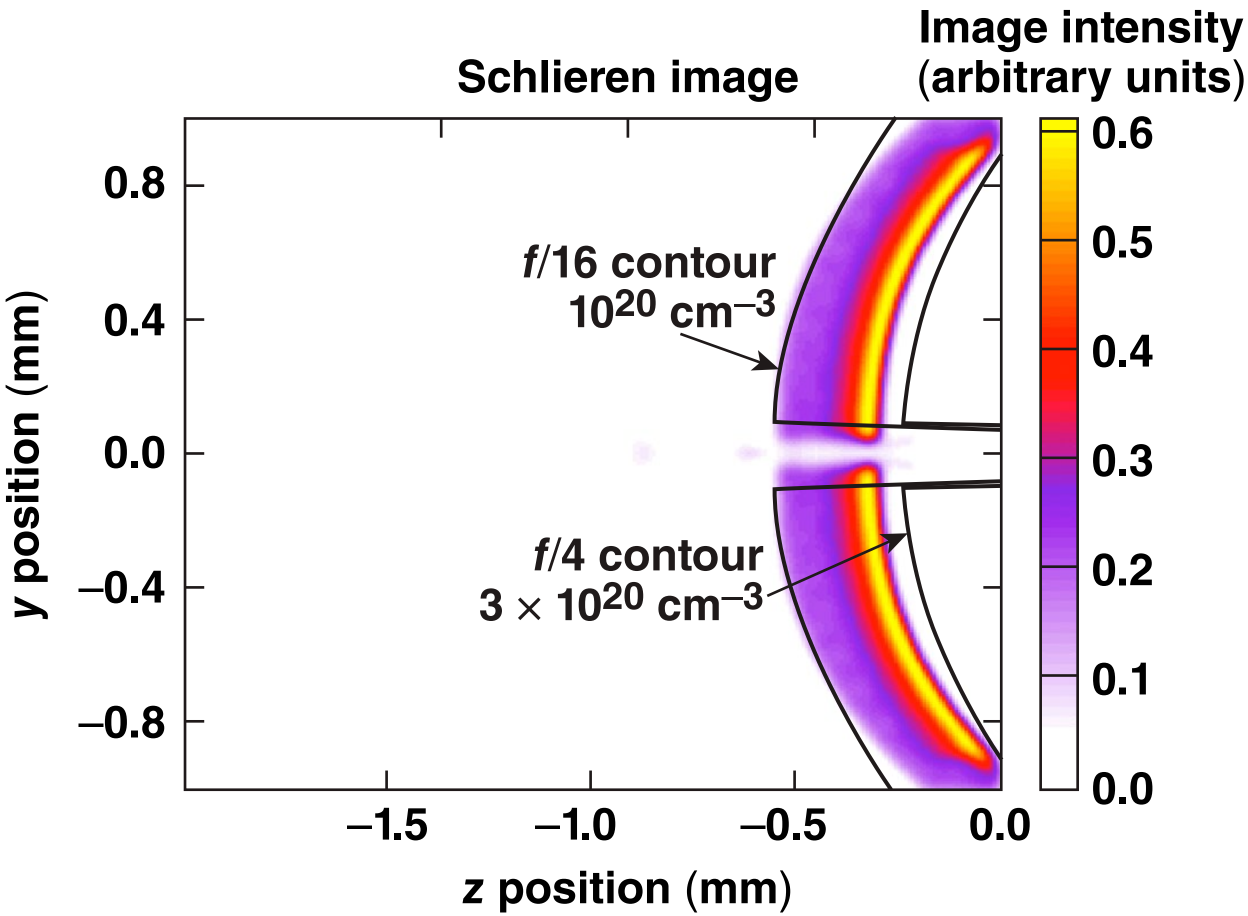
*Photon Engineering, LLC, Tucson, AZ 85711.

A 50-μm channel inside the plasma is resolved by Schlieren



- The resulting ray trace was convolved with a 5-μm point-spread-function (anticipated system imaging resolution) to create an image
- The Schlieren stop filters out rays deflected from 10^{20} cm^{-3} and below, while the aperture stops rays deflected from 3×10^{20} and above

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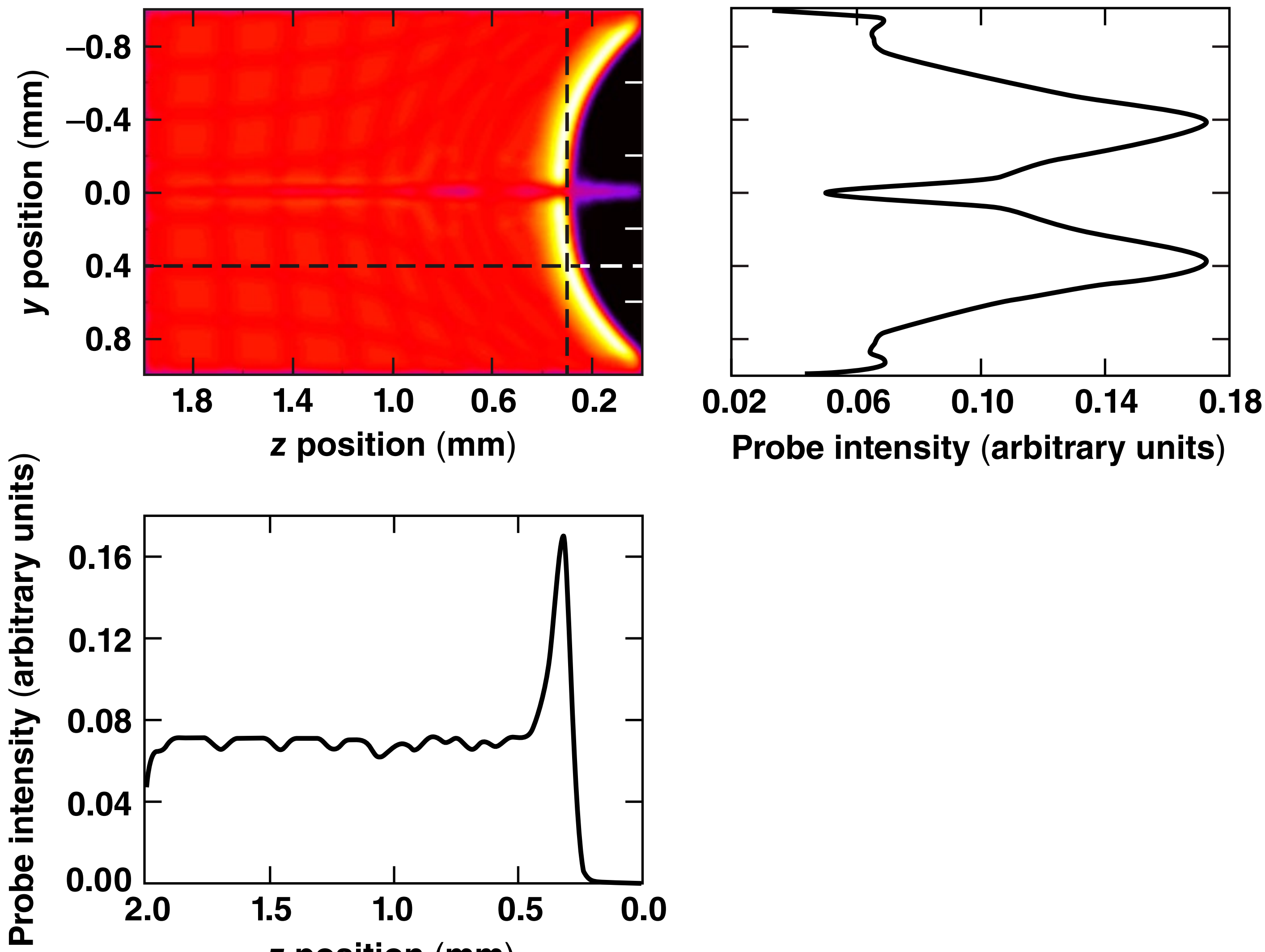
Shadowgraphy more clearly shows the channel in the refracted zone



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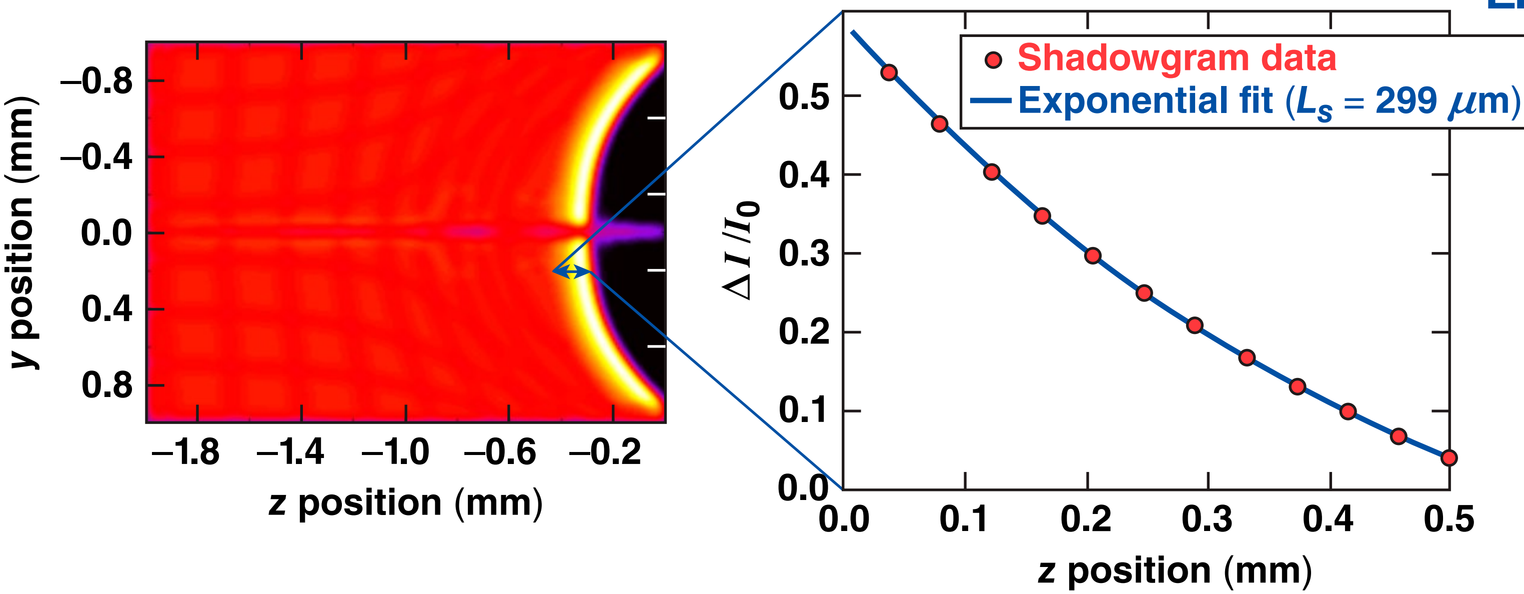
The simulated shadowgraphs can be used infer the density scale length from the simulation



$$\frac{-1}{L}\frac{\Delta I(y',z)}{I_0} = \nabla_\perp^2 \int_0^{\Delta l} \mu(r,z)\,\mathrm{d}l \cong \nabla_\perp^2 \int_0^{\Delta l} \left[1 + \frac{n_e(r,z)}{2n_c}\right]\mathrm{d}l$$

$$n_e(y',z) \propto \frac{\Delta I(y',z)}{I_0}$$

- Cylindrical symmetry
- Plasma of the form $n_e(r,z) = n_p e^{\frac{z}{L}} e^{-r^2/\sigma^2}$
- $n_e/n_c \ll 1$

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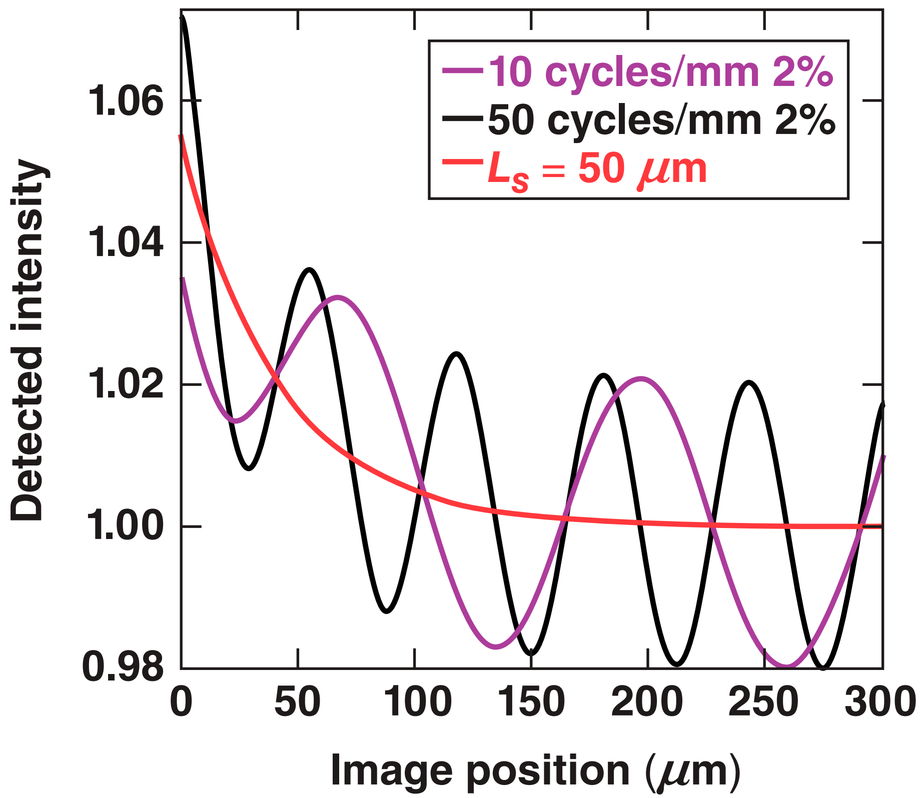
*I. H. Hutchinson, Principles of Plasma Diagnostics (Cambridge University Press, Cambridge, England, 1987), p. 114.

Random intensity variation in low to medium spatial frequencies can cause problems with the analysis



Modulation frequency at 2%	Inferred L_s
0	50 μm
10 cycles/mm	188 μm
50 cycles/mm	43 μm
100 cycles/mm	41 μm

Plasma conditions

L_s	50 μm
Peak density n_p	5×10^{20} W/cm^2
Plasma extent	850 μm

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Summary/Conclusions

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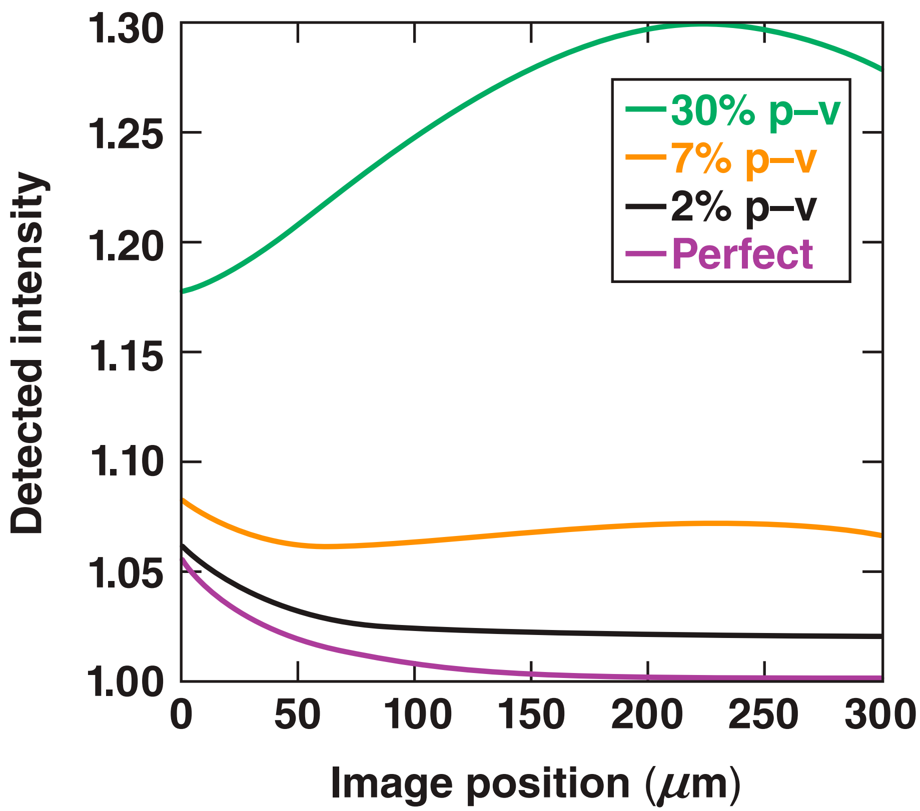
Low-order spatial-frequency modulation leads to errors in shadowgraphy analysis



Modulation amplitude at 2 cycles/mm	Inferred L_s
0	50 μm
2%	33 μm
7%	76 μm
30%	n/a

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