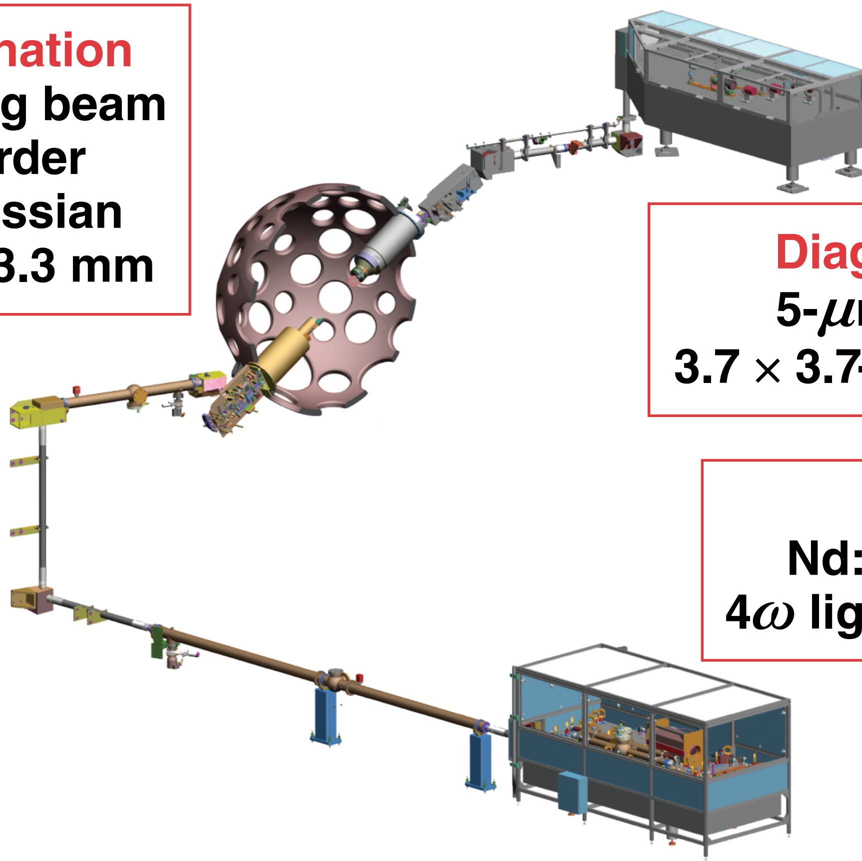
# OMEGA EP 4$\omega$ Diagnostic: System Description and Recent Results

**TCC illumination**
*f*/25 diverging beam
Eighth-order super-Gaussian
Diameter = 3.3 mm



**Diagnostic table**
5-$\mu$m resolution
3.7 × 3.7-mm field of view

**Laser**
Nd:glass ~120 mJ
4$\omega$ light ~20 mJ (10 ps)

D. Haberberger
University of Rochester
Laboratory for Laser Energetics

Omega Laser Facility
Users Group Workshop
Rochester, NY
24–26 April 2013

Summary

# The 4$\omega$ diagnostic on OMEGA EP has been activated and is ready for use by external users

- A 10-ps, 20-mJ, 4$\omega$ probe laser is installed and in use on the OMEGA EP target chamber
- An *f*/4 system provides access to high-density, large-scale-length laser-produced plasmas
- The system was designed for advanced optical diagnostics
  - refractometry using angular spectral filters (ASF) (in use)
  - schlieren and shadowgraphy (in use)
  - grid-imaging refractometry (future)
  - interferometry (future)
  - polarimetry (future)
- Advanced optical design tools are being developed to provide synthetic diagnostic images for experimental setup and analysis

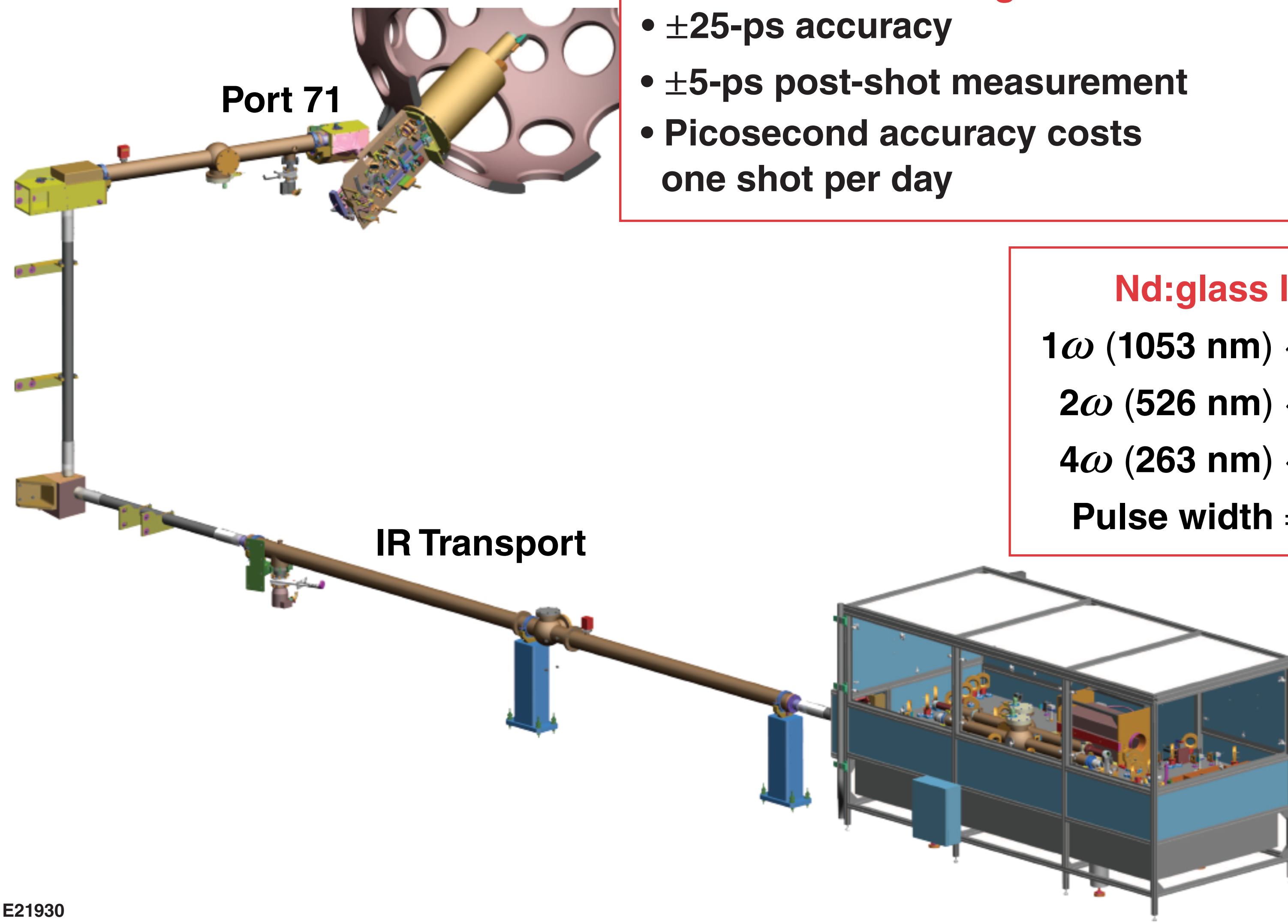
**The diagnostics coupled with detailed optical modeling of the system provide a novel diagnostic platform for detailed plasma measurements.**

# Collaborators

R. Boni, M. Barczys, J. Brown, R. G. Roides, R. Huff, S. Ivancic,
M. Bedzyk, R. S. Craxton, F. Ehrne, 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

# The 4$\omega$ probe beam is generated by converting an Nd:glass laser pulse to its fourth harmonic




**Timing**

- ±25-ps accuracy
- ±5-ps post-shot measurement
- Picosecond accuracy costs one shot per day

**Nd:glass laser**

1$\omega$ (1053 nm) ~ 120 mJ

2$\omega$ (526 nm) ~ 60 mJ

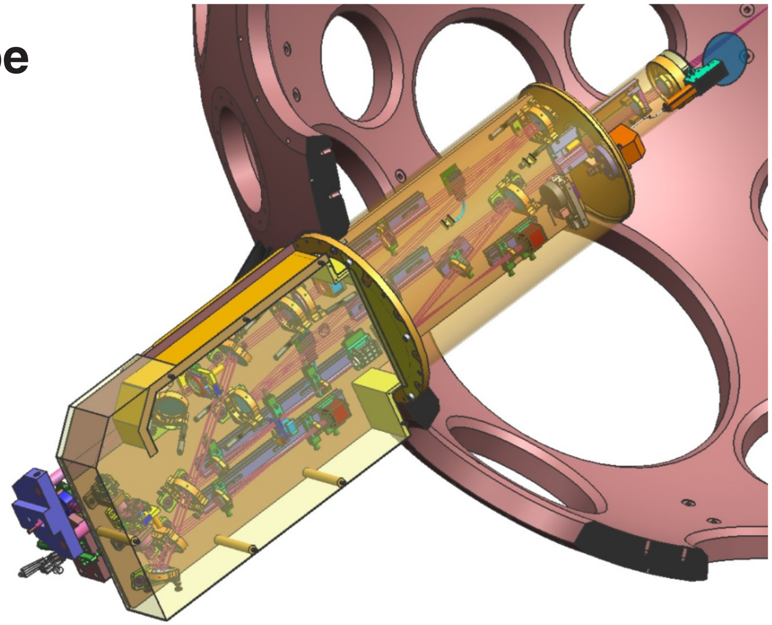
4$\omega$ (263 nm) ~ 20 mJ

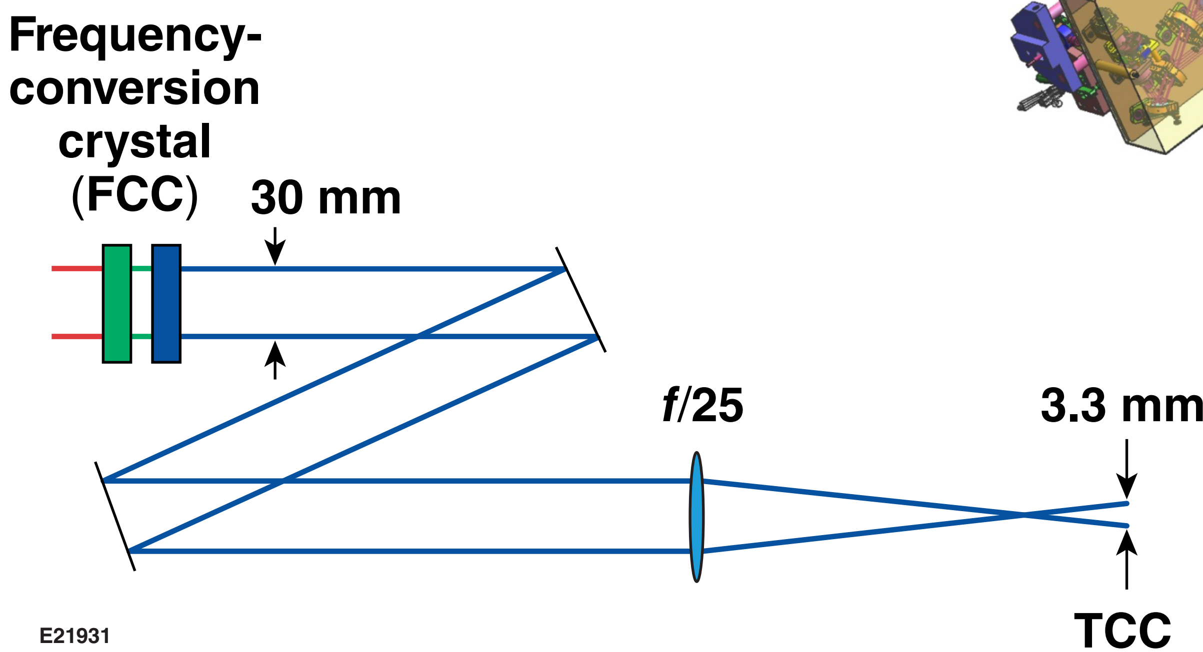
Pulse width = 10 ps

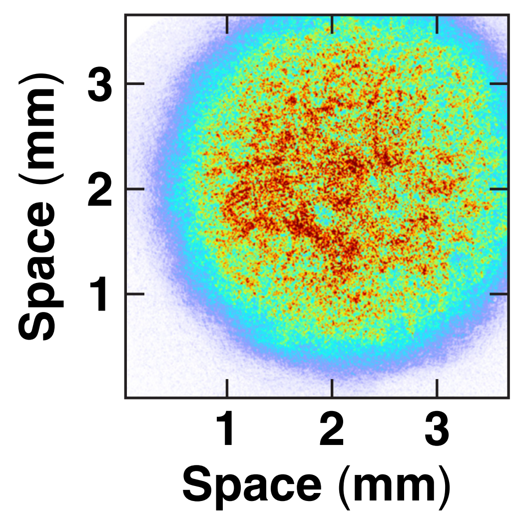
E21930

# The 4$\omega$ probe laser system delivers a 3.3-mm spot to target chamber center in a super-Gaussian beam shape

- Eighth-order super-Gaussian beam shape
- System can be focused at target chamber center (TCC)
- Enters from Port 71 chamber west

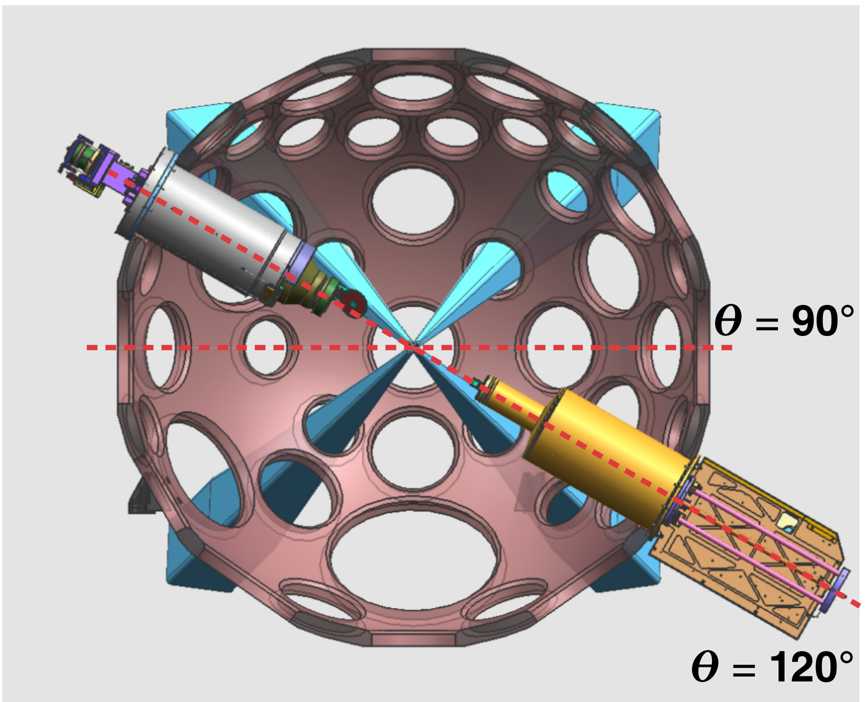


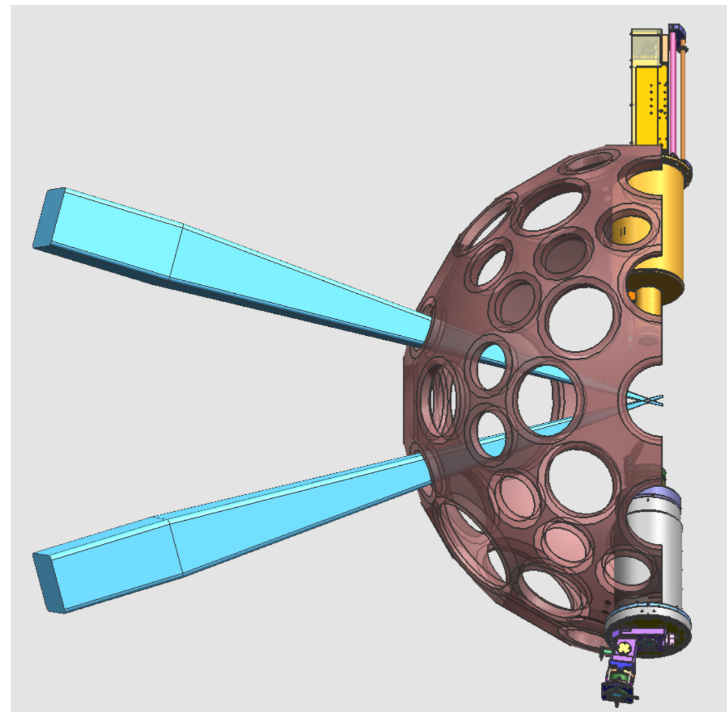



E21931

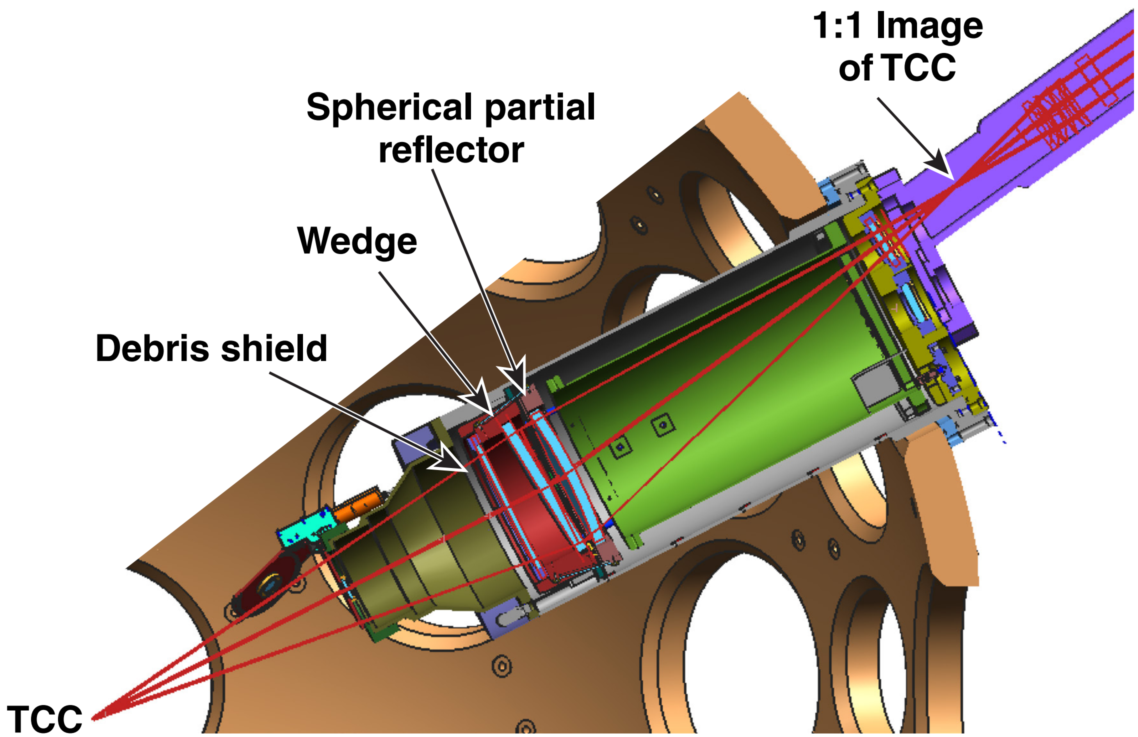
# The propagation vector through the target chamber is orthogonal to the backlighter and centroid of UV beams



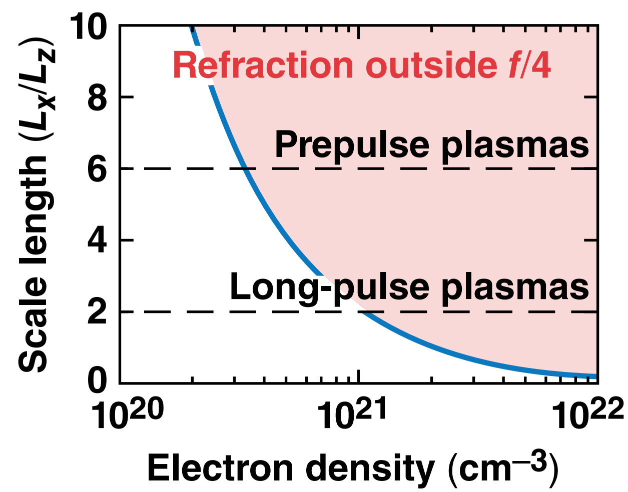
**The 4$\omega$ probe beam is available in VisRad and propagates 1 mm north (toward Port 45) of the TCC. Please contact Dan Haberberger or Dustin Froula for help with planning experiments.**

# The $f/4$ collection optics deliver a diffraction-limited image accessing plasma densities near quarter critical for $3\omega$ light



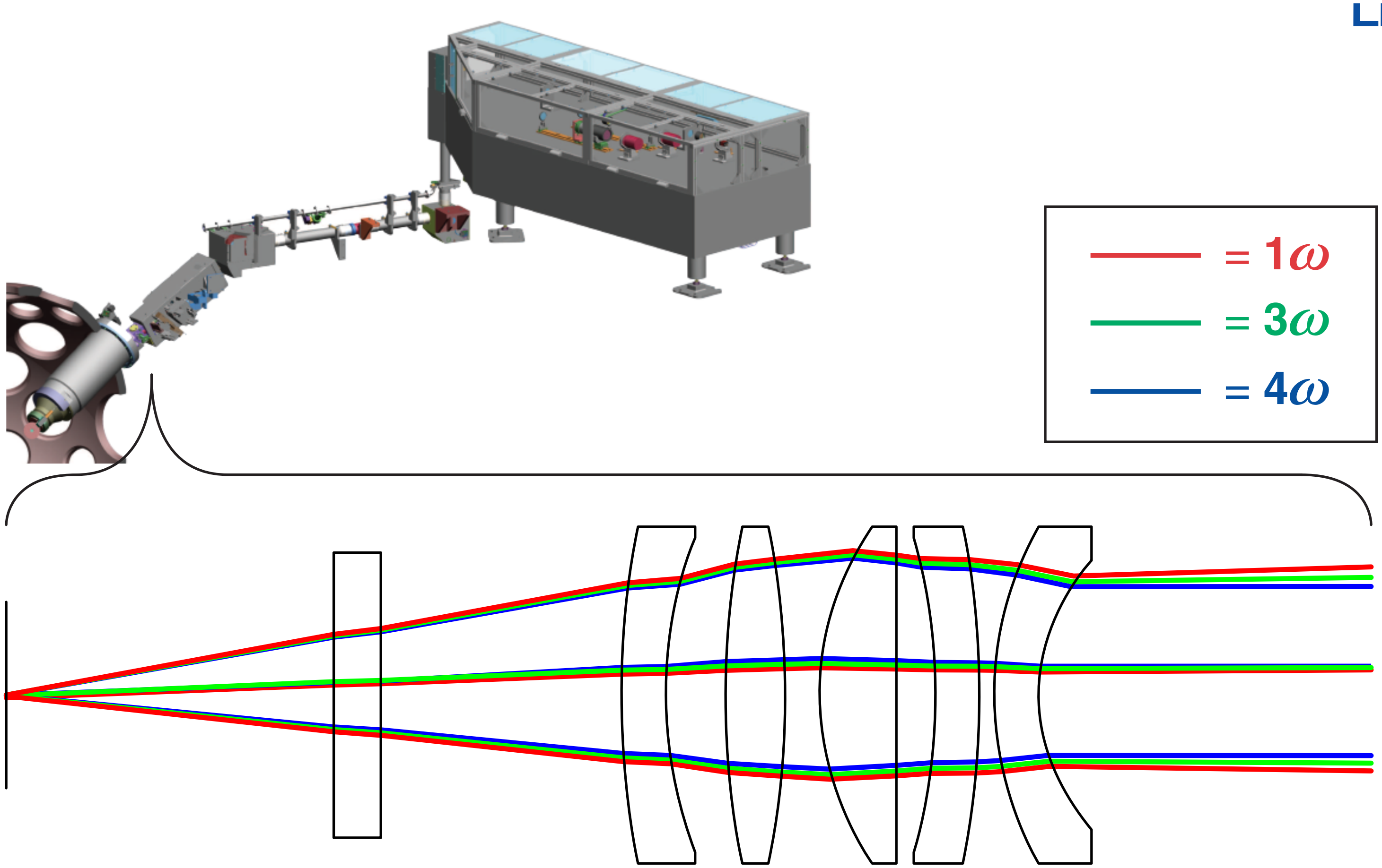

*f*/4 catadioptric collection system

- Diffaction limited performance
- Achromatic focusing
- Attenuate $1\omega/3\omega$




E21933

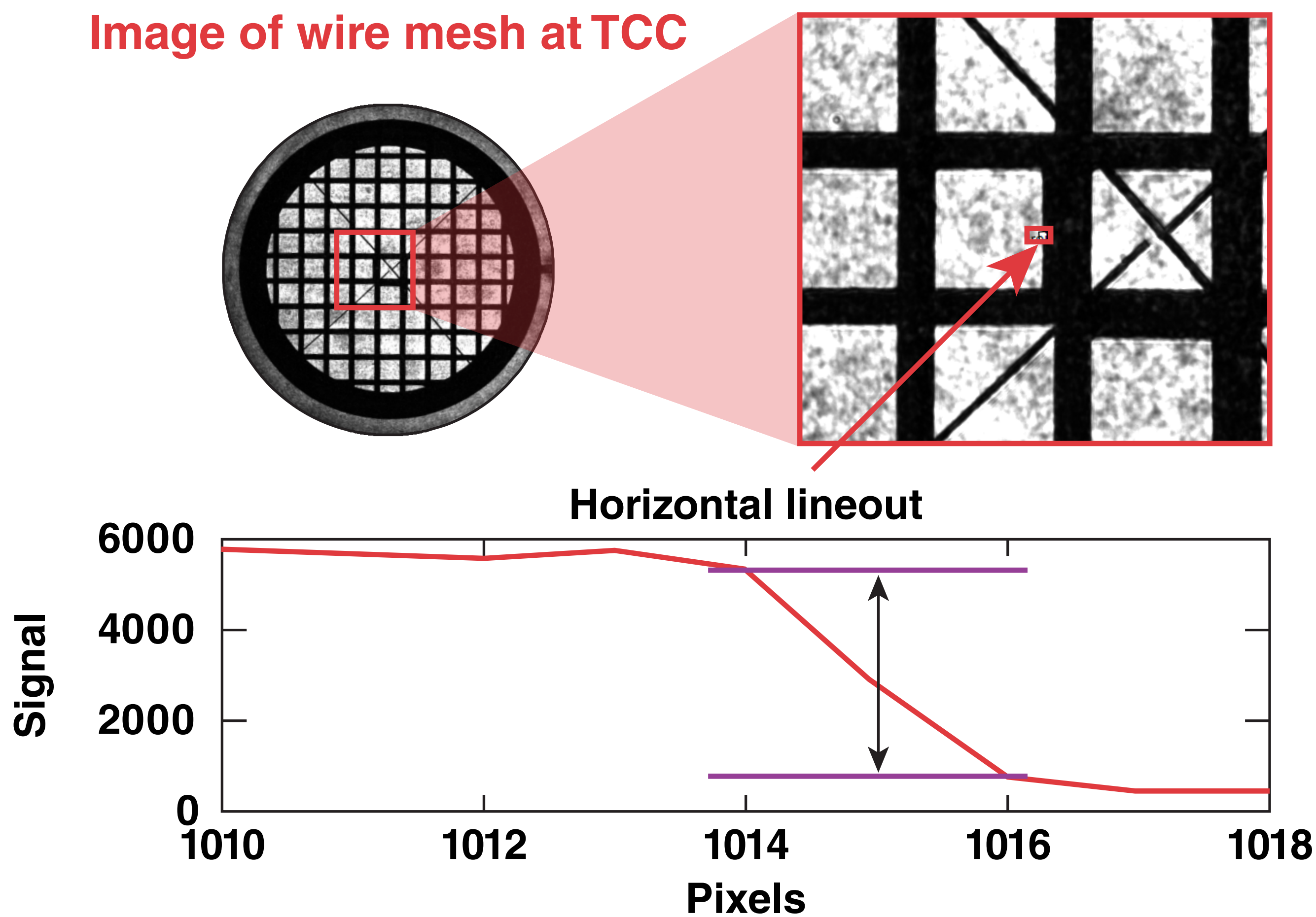
# The catadioptric collection and five-element collimator provide quasi-achromatic colimation across 1$\omega$, 3$\omega$, and 4$\omega$ for efficient filtering




**The collimated section provides excellent bandpass rejection to overcome 1$\omega$ and 3$\omega$ drive laser emission (10,000:1 outside 2-nm bandpass.)**

E21934

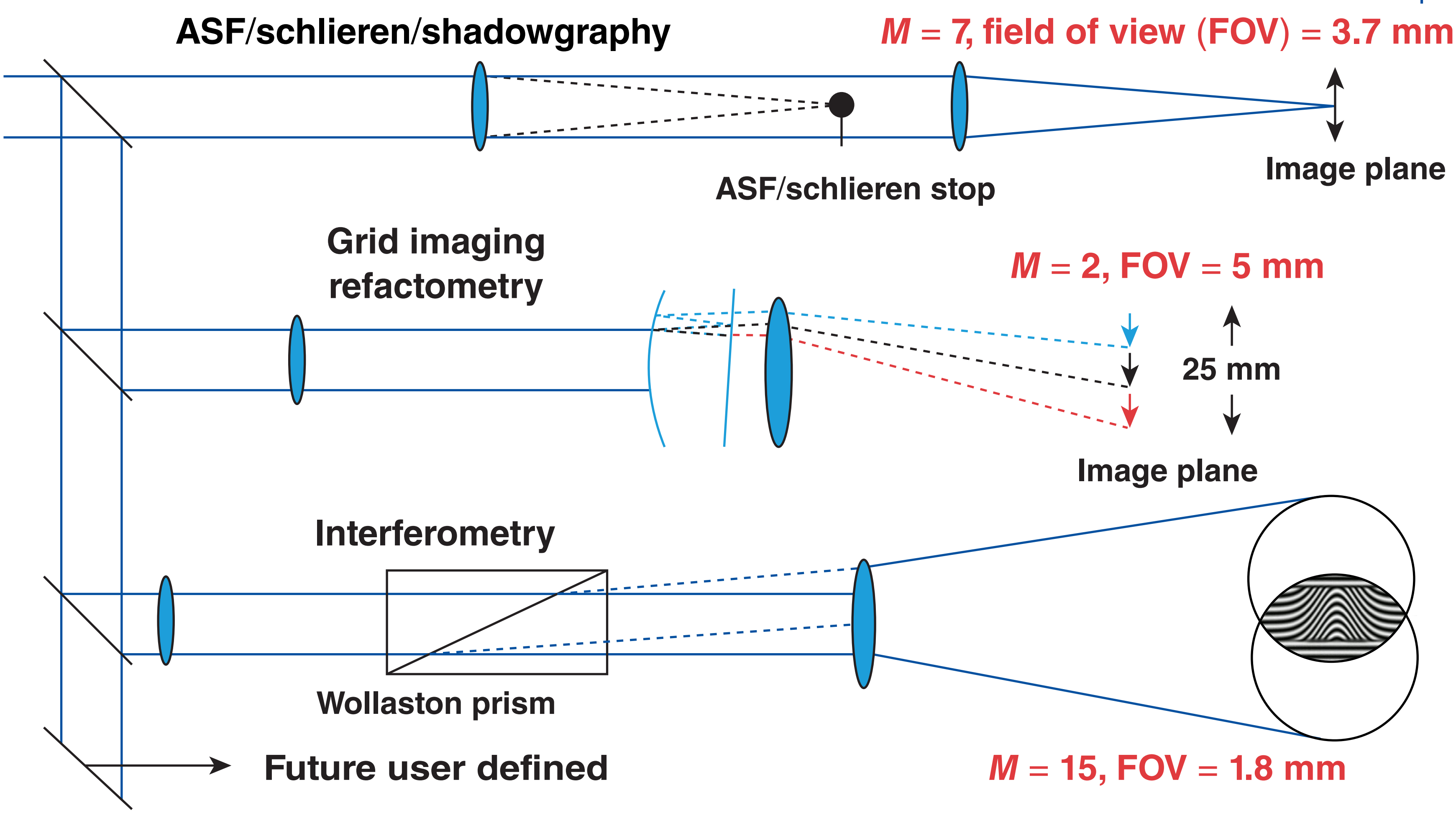
# A wire mesh at TCC demonstrates 5-$\mu$m imaging resolution over a 3-mm field of view




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

E21935

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

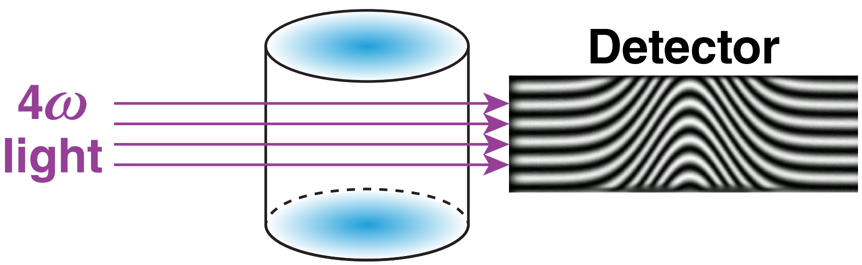



**The 55-sq.-ft. diagnostic table provides space for diagnostic expansion.**

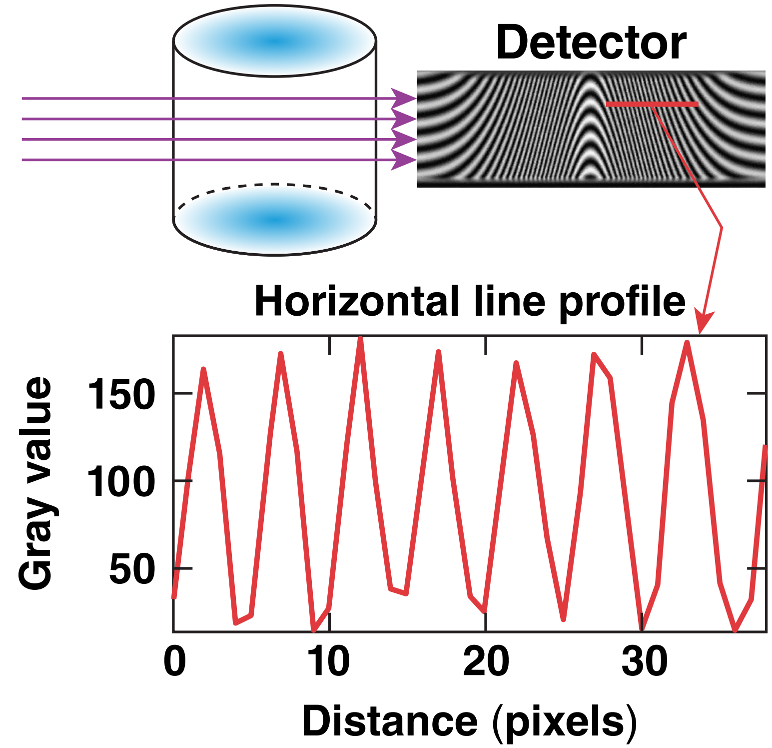
E21936

# Interferometry measures the plasma-density profile up to the resolution limit of the fringes

**Gaussian Plasma Column**
**FWHM = 0.2 mm**
$n_{e,0}$ = **2.0** × $10^{20}$ cm$^{-3}$




**Gaussian Plasma Column**
**FWHM = 0.2 mm**
$n_{e,0}$ = **8.0** × $10^{20}$ cm$^{-3}$



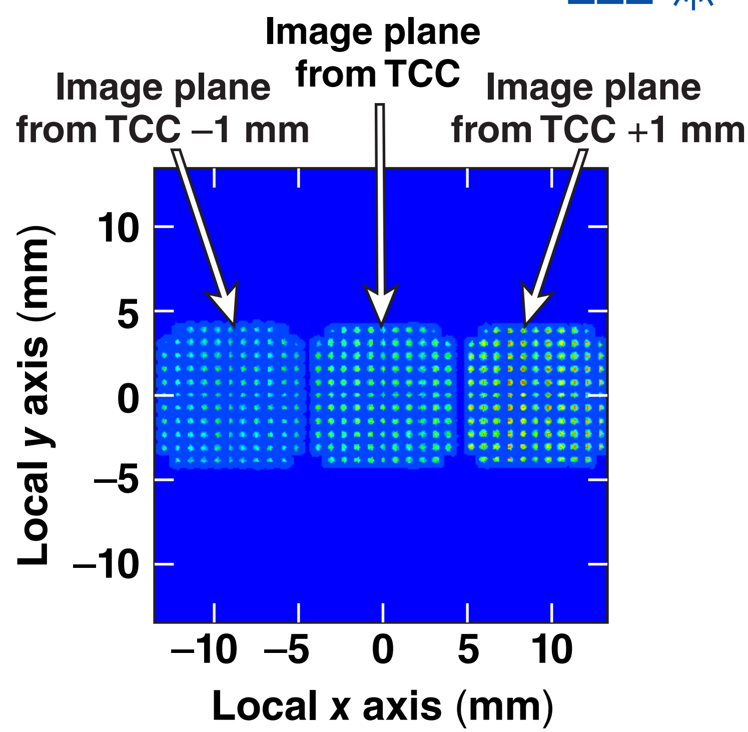

**Danger zone:**
**close to the sampling limit!**

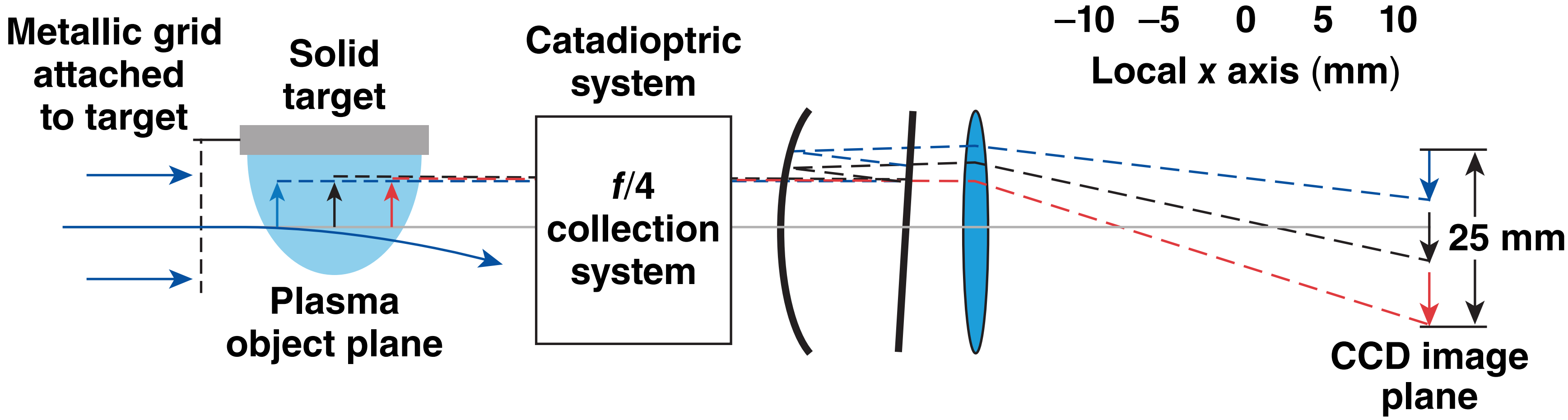
- **Short-pulse plasmas having a FWHM ~200 $\mu$m are limited to densities <$10^{21}$ cm$^{-3}$**
- **UV long-pulse plasmas having FWHM ~1 mm are limited to densities ≤$10^{20}$ cm$^{-3}$**

Courtesy of N. Kugland, H-S. Park

# Grid-imaging refractometry (GIR) measures the refraction of beamlets at three locations within the plasma

- GIR extends the density measurements to $10^{21}$ $cm^{-3}$ in long-scale-length plasmas
- Three longitudinal objects in the plasma are imaged to a single charge-coupled device (CCD)
- The system is designed to have <50-$\mu$m resolution over a 5-mm field of view
- Magnification of 2

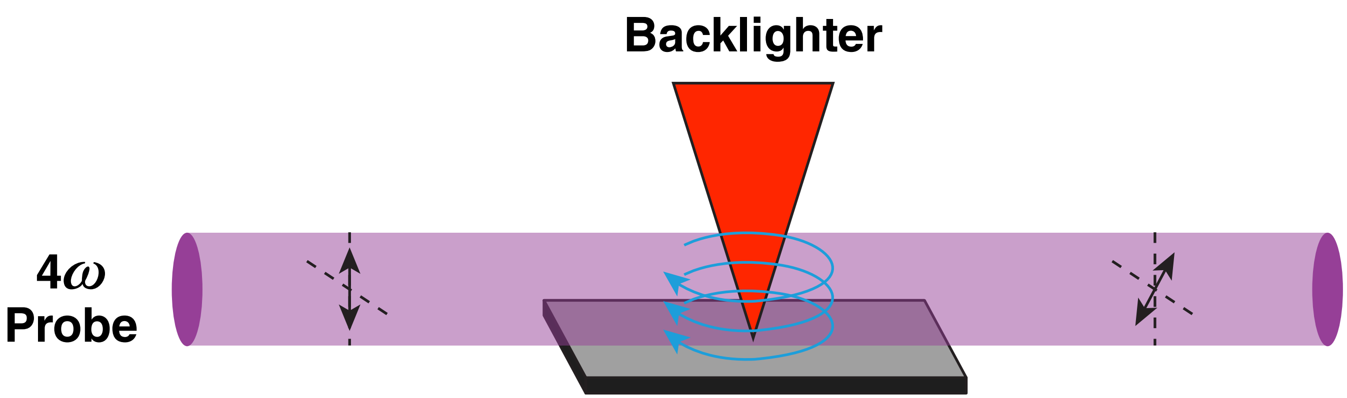



E19800a

*R. S. Craxton *et al.*, Phys. Fluids B 5, 4419 (1993).

# Polarimetry can be used to measure externally and laser-generated magnetic fields

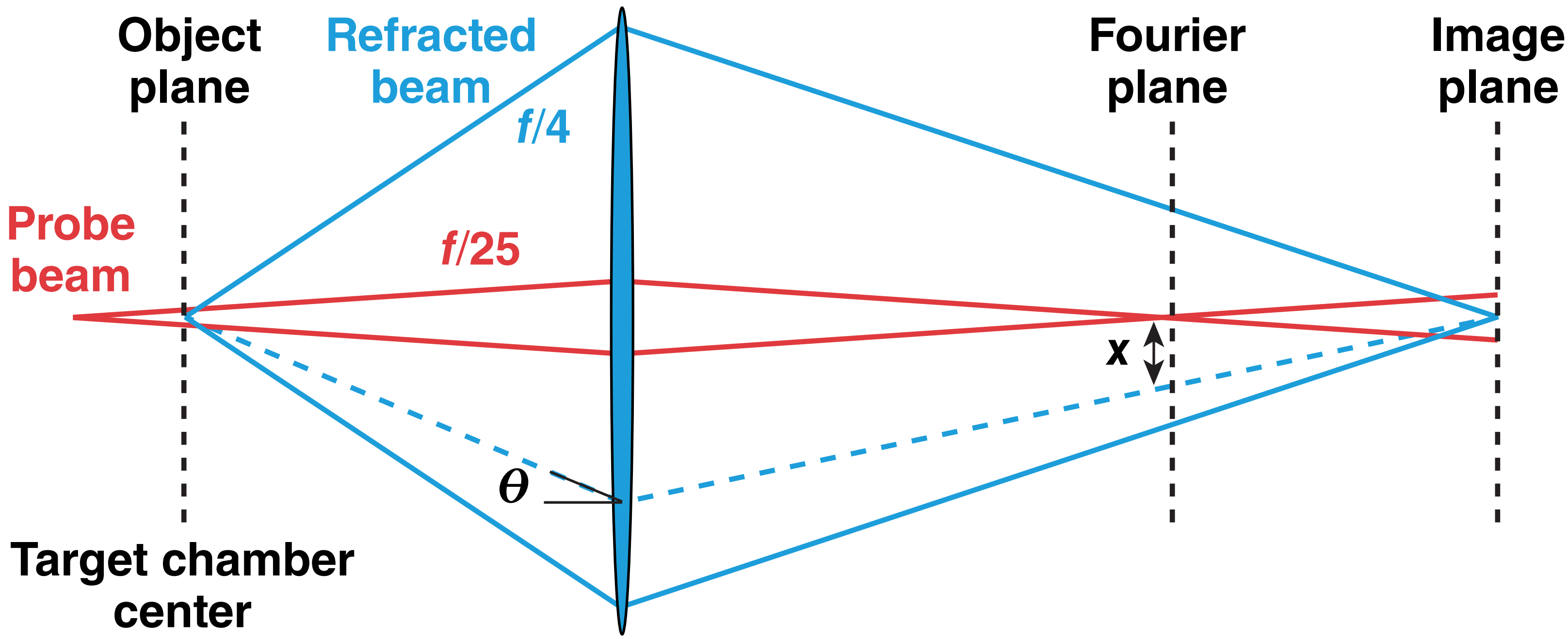



**Faraday effect**

$$\Delta\theta = \frac{e}{2m_e c}\int_{-\infty}^{\infty}\frac{n_e}{n_c}B\cdot dl = 2.62\times10^{-17}\lambda^2\int_{-\infty}^{\infty}n_e B_{\parallel}\,dl$$

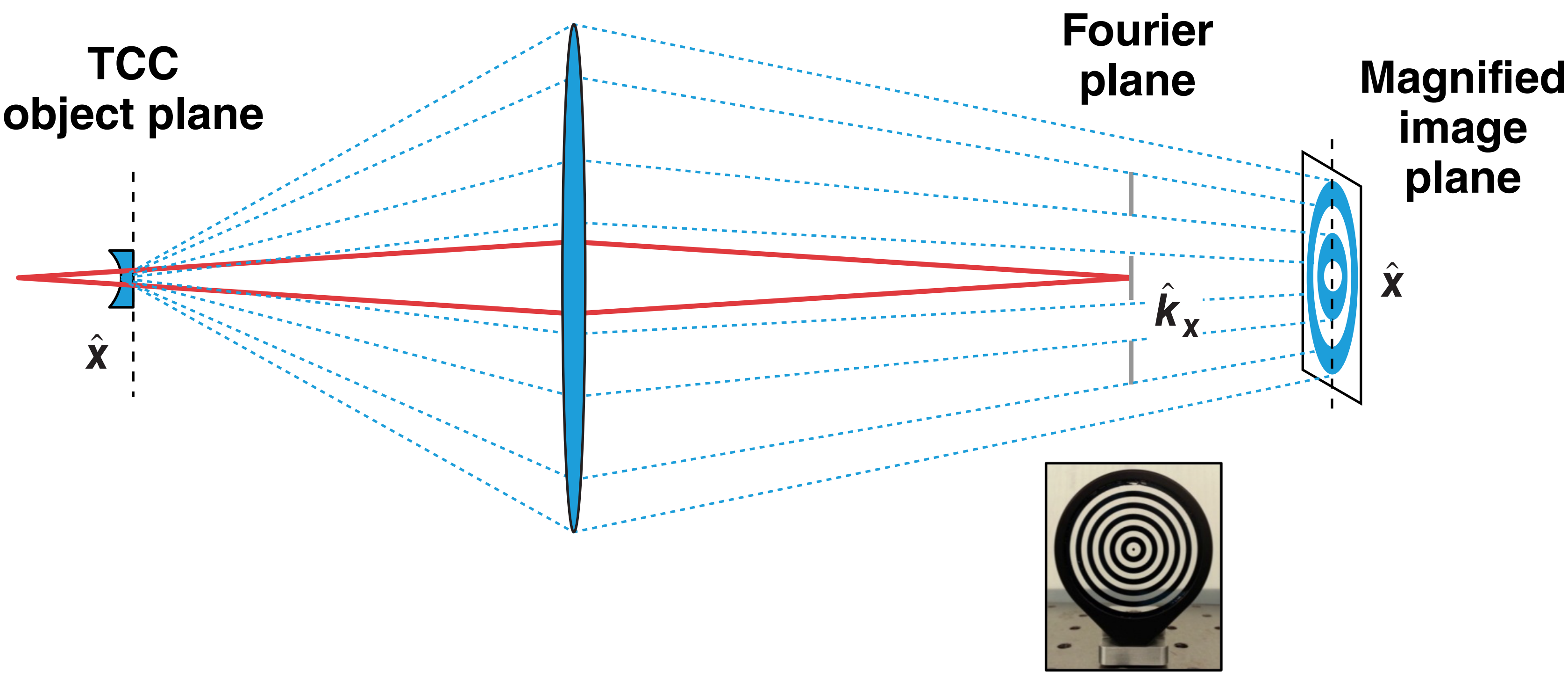
- **We would like input from the community on the requirements for polarimetry.**
- **The sensitivity to the polarization rotation angle of the 4$\omega$ probe beam is under investigation.**

# Refractometry using angular spectral filters (ASF's) maps the refraction of the beam at TCC to contours in the image plane




- Refraction angle is mapped to space in the probe beam's Fourier plane
- A mask at the Fourier plane selectively filters certain *k*-space components of the refracted beam
- The beam returns to the image plane, which now maps refractive angle to real space

# Using a bullseye ASF creates a contour map of refractive angle

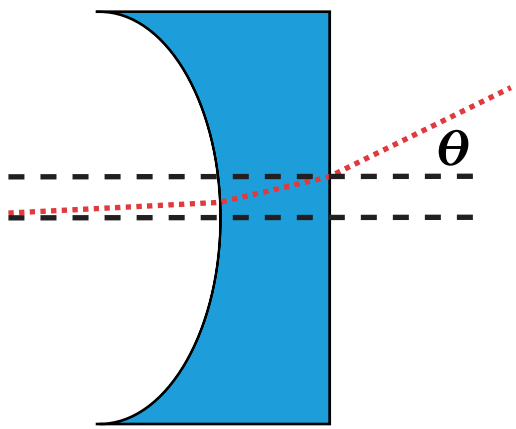



**The edges of the rings represent contours of constant refraction at a specific angle.**

E21940

# This concept is demonstrated experimentally by placing a negative lens at TCC

**Negative spherical lens at TCC**




**Round beam shape at Fourier plane**

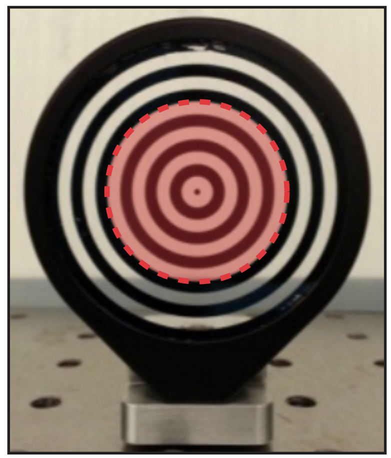
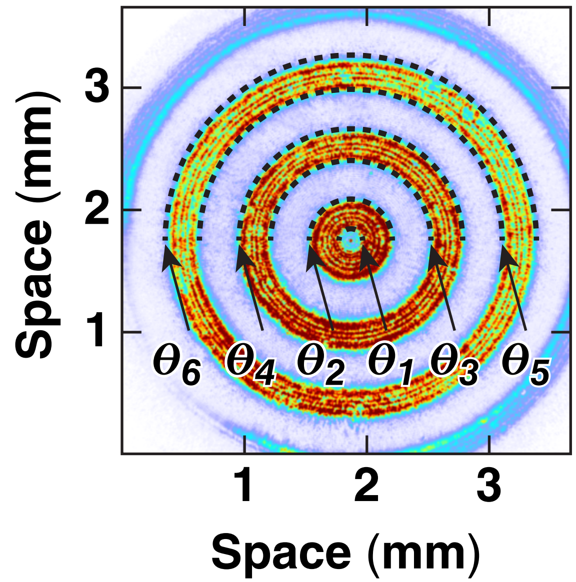


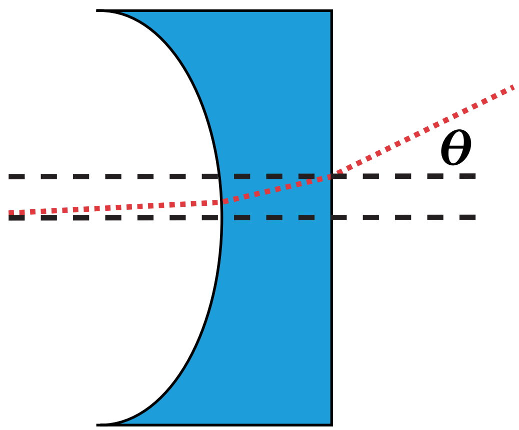
**Image plane using a spherical lens**




**The ASF calibration lens image maps a specific refractive angle to each band in the filter.**

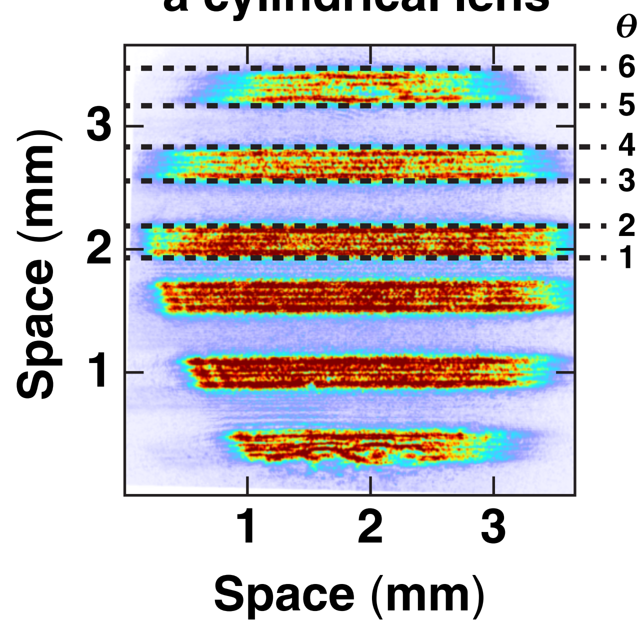
# To further illustrate the refraction mapping, a cylindrical lens was used to refract the probe beam in the vertical direction

**Negative cylindrical lens at TCC**




**Round beam shape at Fourier plane**

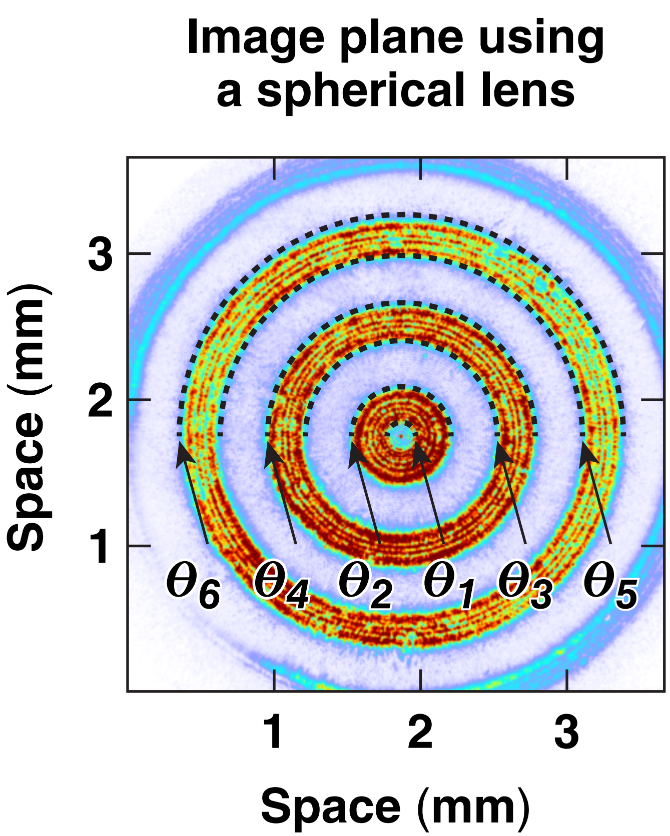
**Image plane using a cylindrical lens**

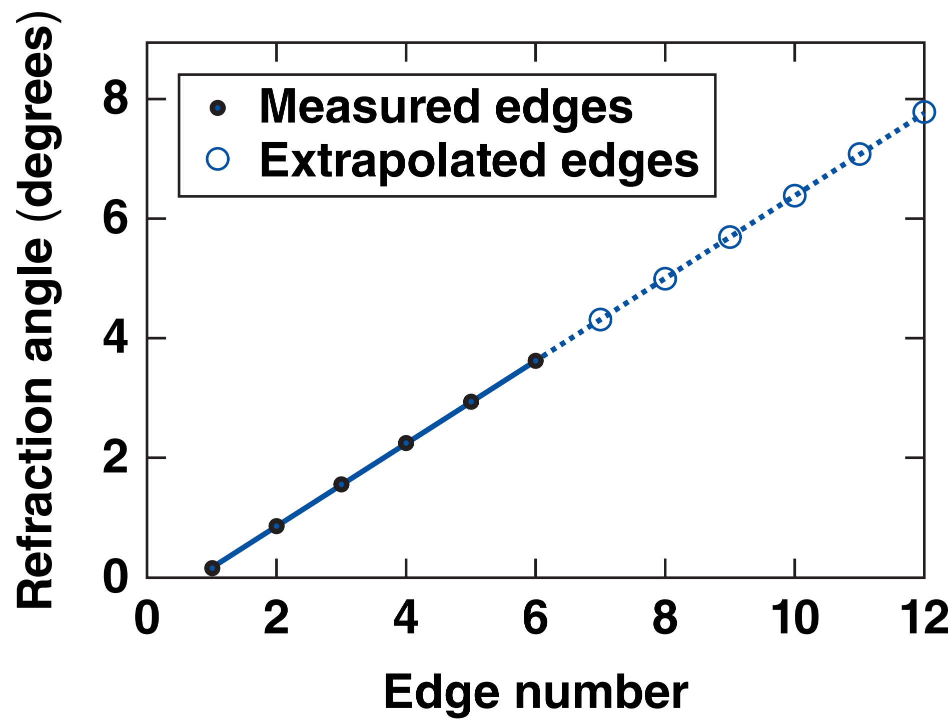



**The ASF calibration lens image maps a specific refractive angle to each band in the filter.**

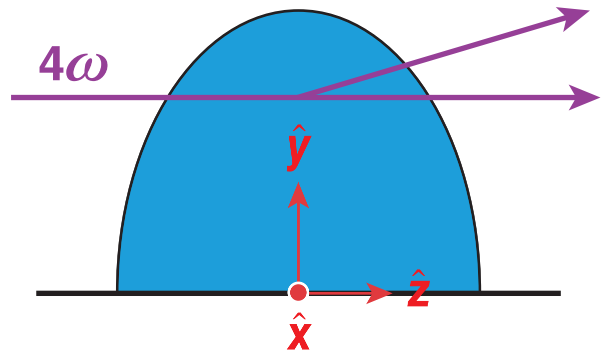
E21941a

# The diagnostic is calibrated using the negative spherical lens



# The scale length of the plasma can be analytically deduced assuming a simple density profile

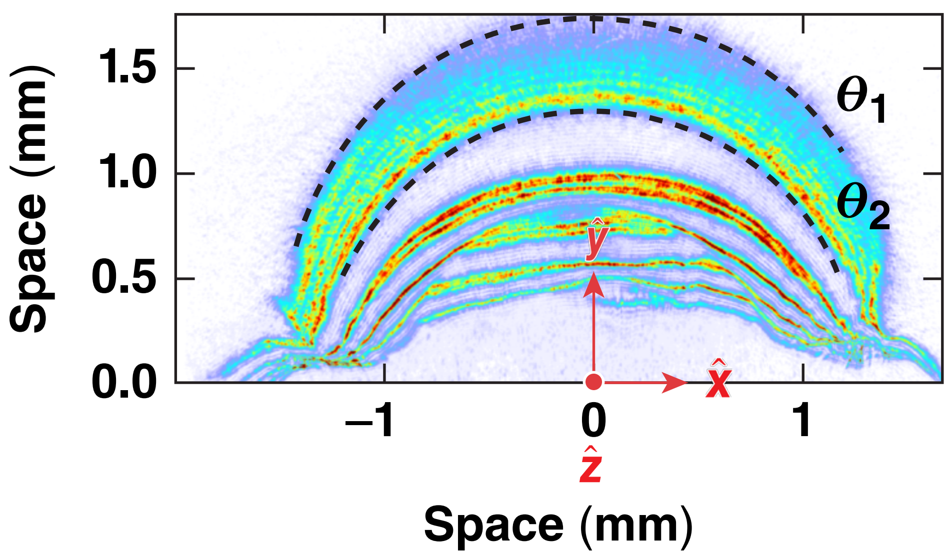



$$\theta_r = \frac{\lambda}{2\pi}\frac{d\phi}{dr}$$

$$\phi = \frac{2\pi}{\lambda}\int_{-\infty}^{\infty}\left(1-\frac{n_e}{2n_{cr}}\right)dz$$

$$n_e(x,y,z) = \exp\left[-\frac{y}{L_s}-\left(\frac{x^2+z^2}{\sigma^2}\right)\right]$$

Shot: 13876



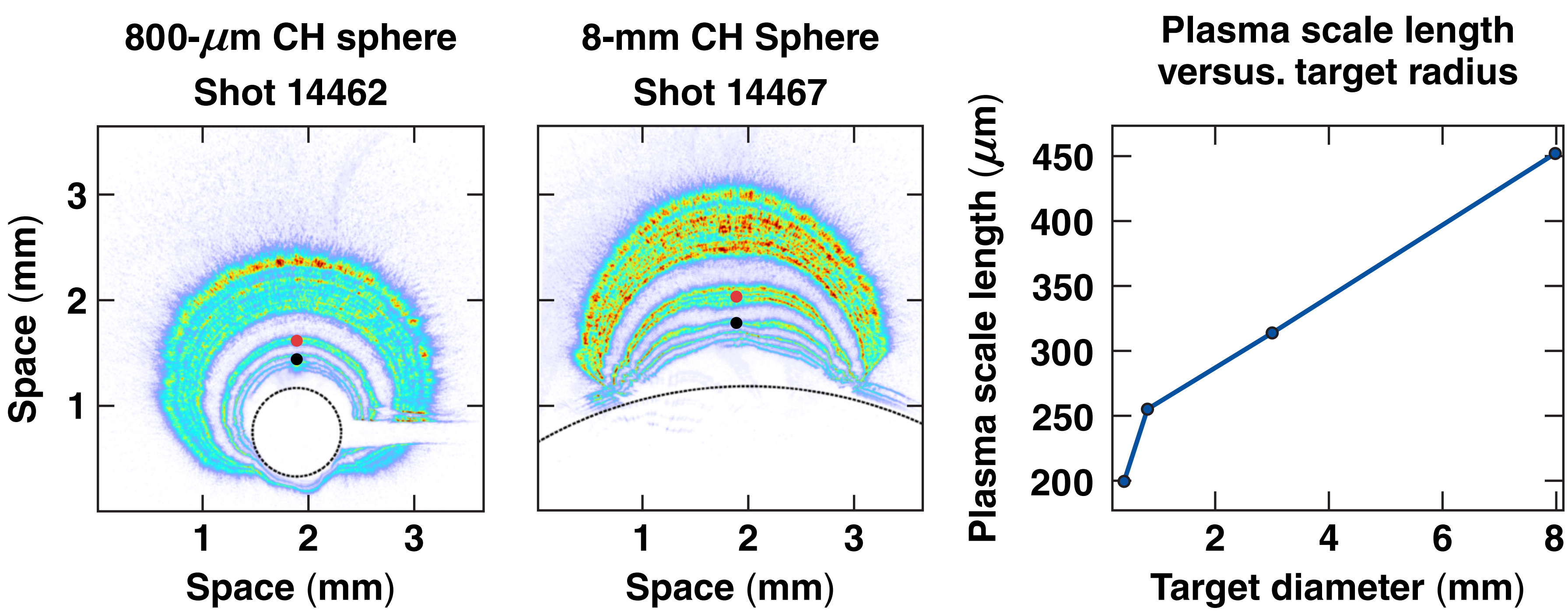

$$L_s = -\frac{y_2 - y_1}{\ln\left(\frac{\theta_2}{\theta_1}\right)}$$

E21943

# Spherical targets were used to vary the plasma density scale length

$\theta_1 = 2.01°$

$\theta_2 = 3.47°$

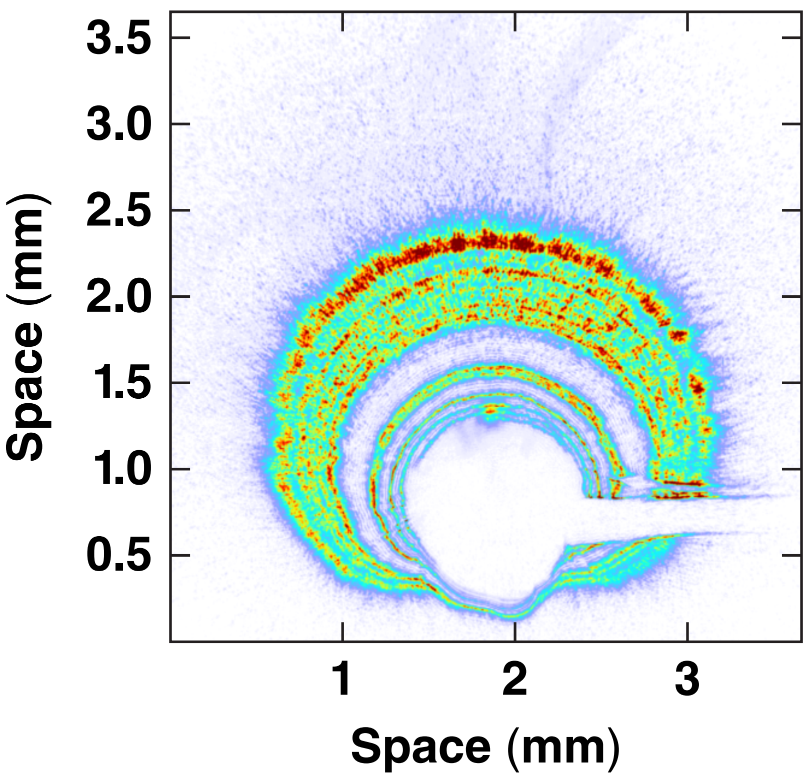



E21944

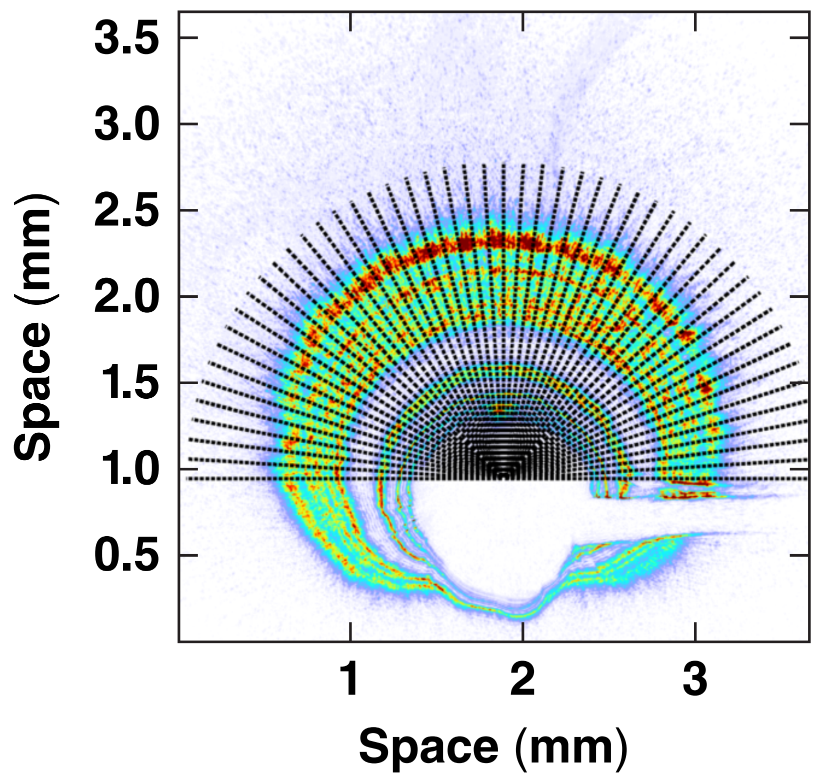
# The plasma density profile can be calculated by Abel inversion of the phase

$$\phi = \frac{2\pi}{\lambda}\int \theta_r dr$$

Original ASF image



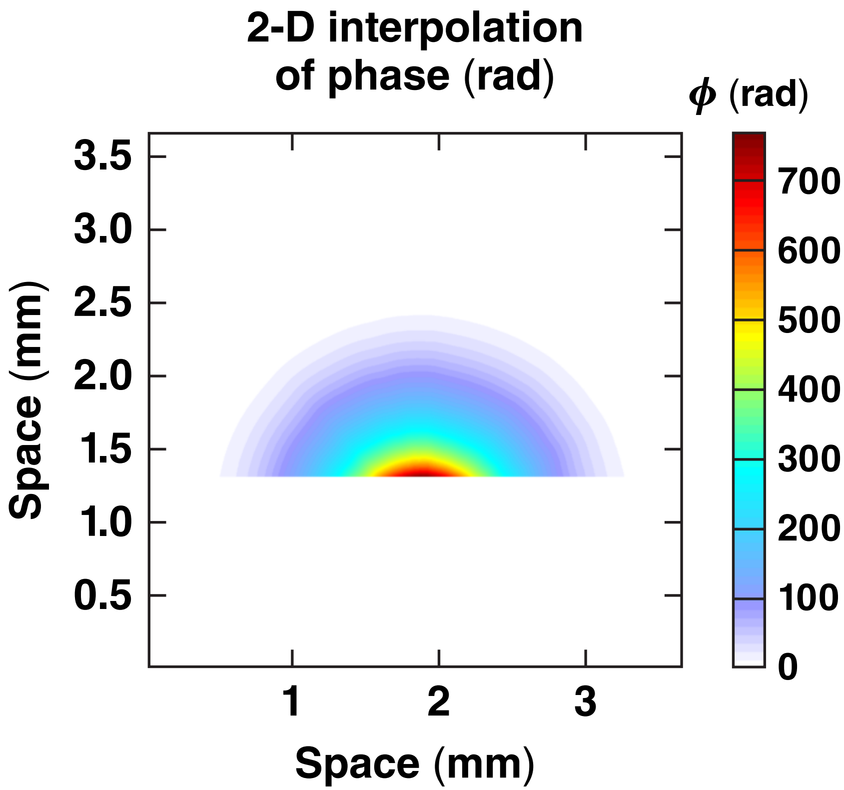

Integrate radial lineouts of refraction angle to obtain phase

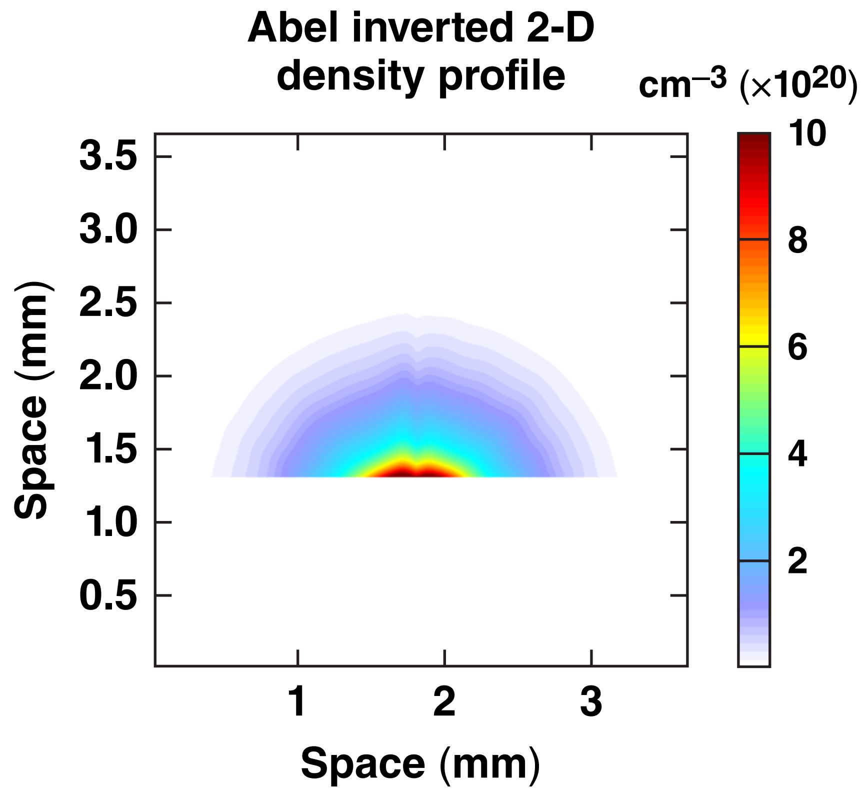



E21944a

# The radial lines of phase are interpolated over all pixels of the 2D map to prepare for Abel inversion

$$\phi = \frac{2\pi}{\lambda}\int_{-\infty}^{\infty}\left(1-\frac{n_e}{2n_{cr}}\right)dz$$

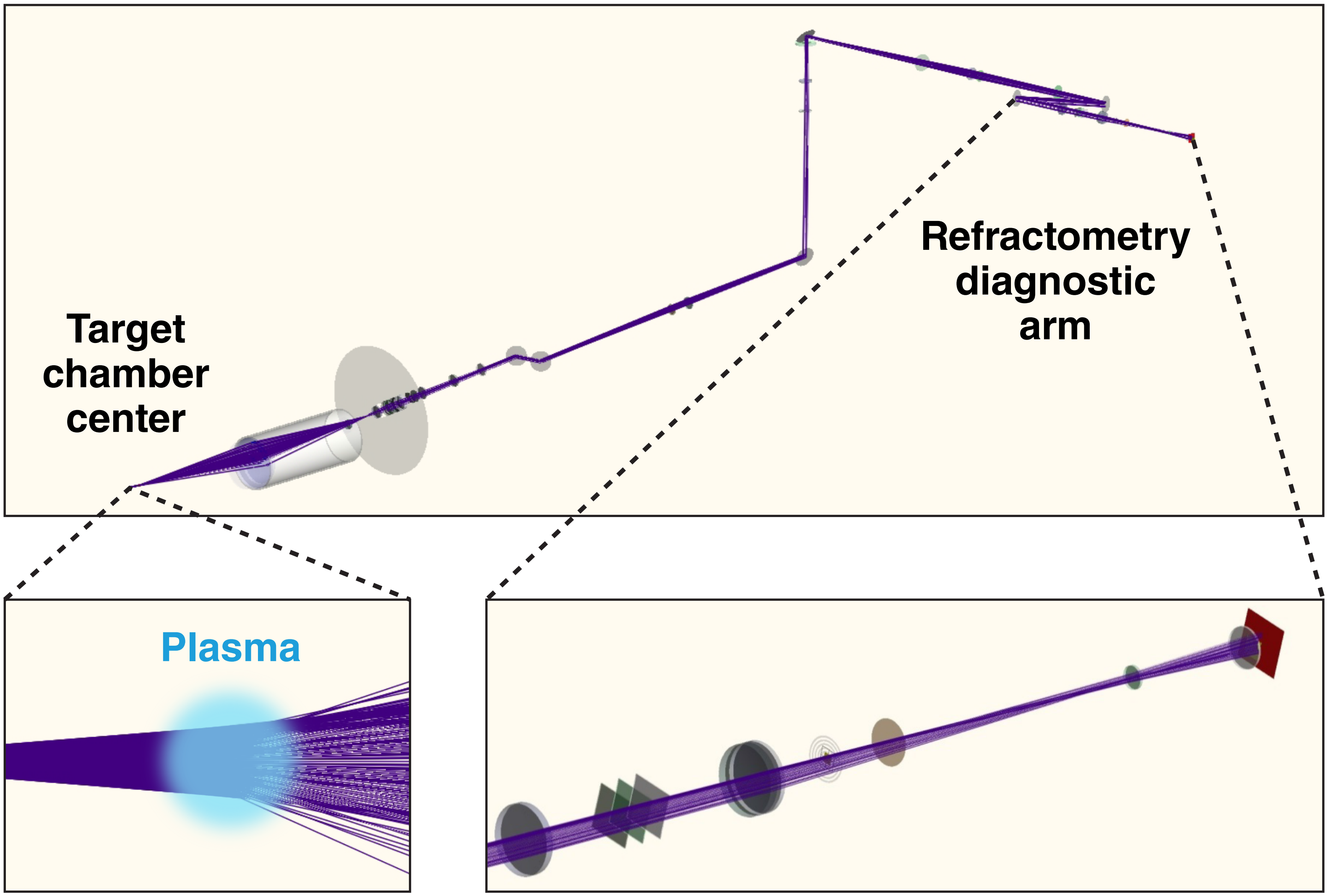



**The assumption of straight propagating of the probe ray plus other numerical errors motivate an accurate simulation model.**

E21944b

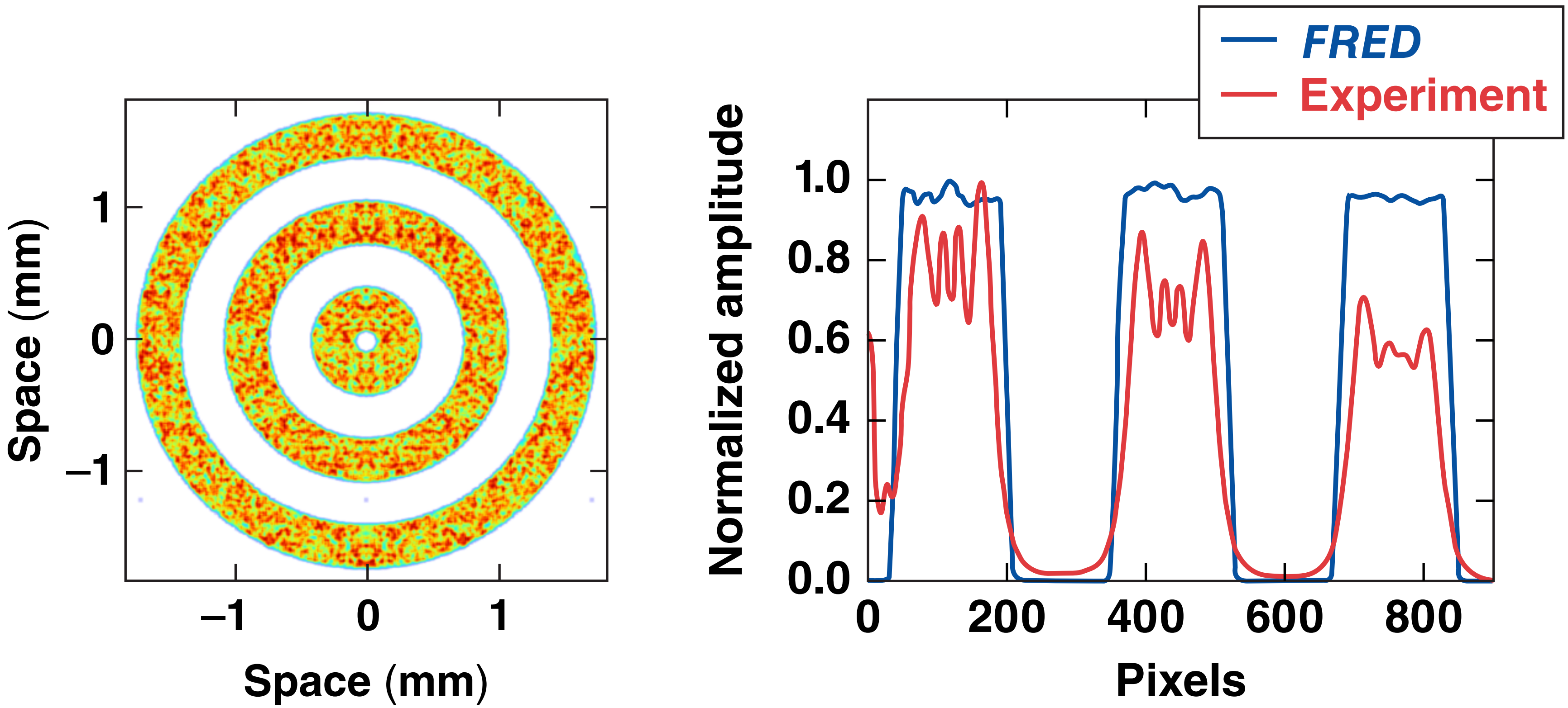
# Optical modeling in *FRED* supports the analysis of the 4$\omega$ probe diagnostic system




E21945

Courtesy of S. Ivancic

# The optical model is calibrated by matching the position of the Fourier plane, image plane, and magnification

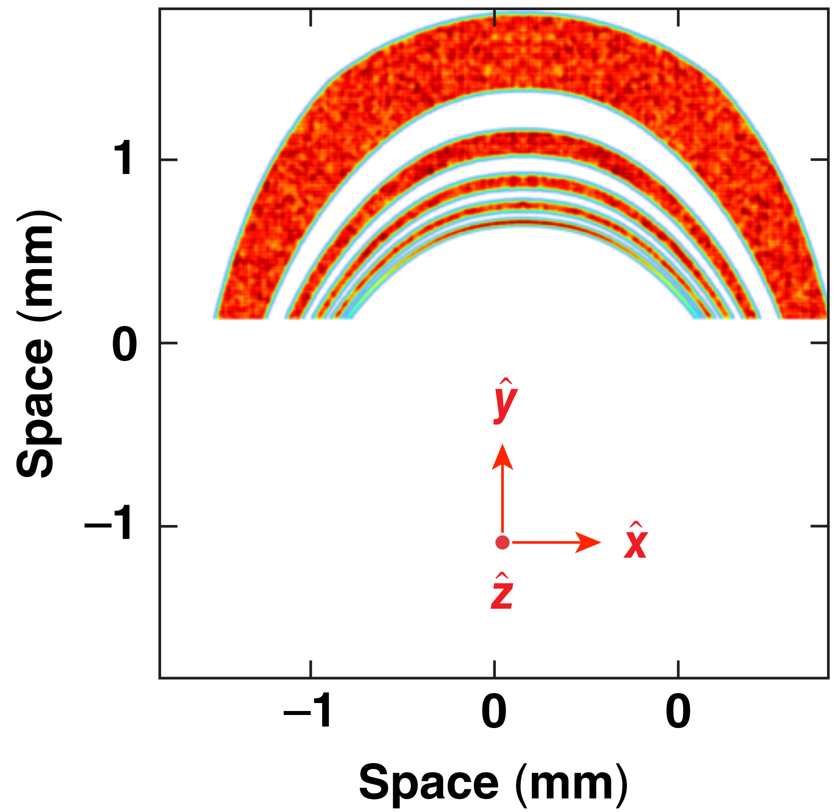



**The calibration lens images produced by the optical model agree with the experimentally obtained images.**

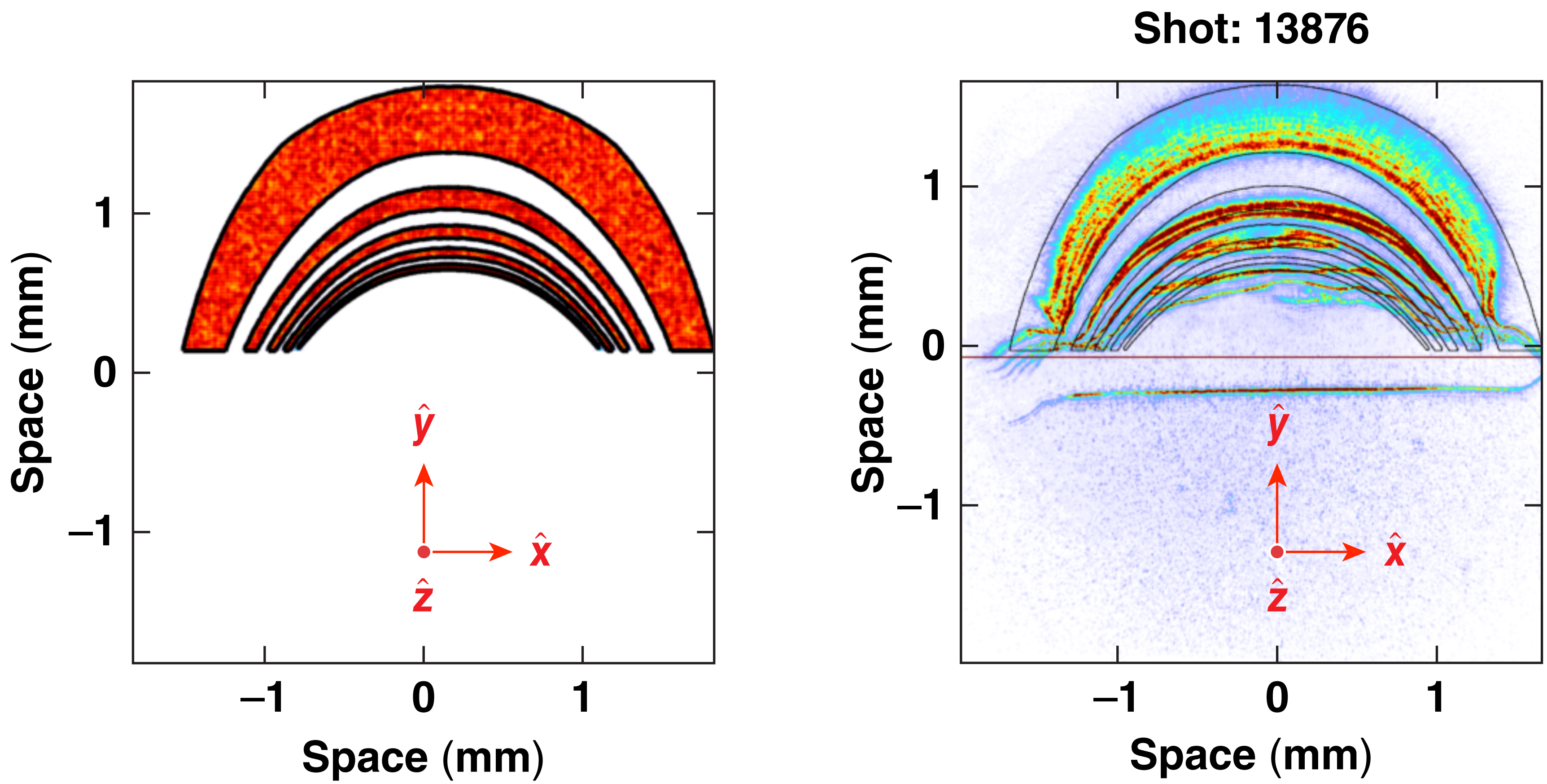
E21946

# *FRED* was used to model a UV-irradiated flat foil plasma expansion simulated by *DRACO*

- A 3-D plasma profile was created in *FRED* from the 2-D *DRACO* profile assuming axial symmetry
- Ray tracing through the plasma (and the 4$\omega$ diagnostic model) produced the ASF image

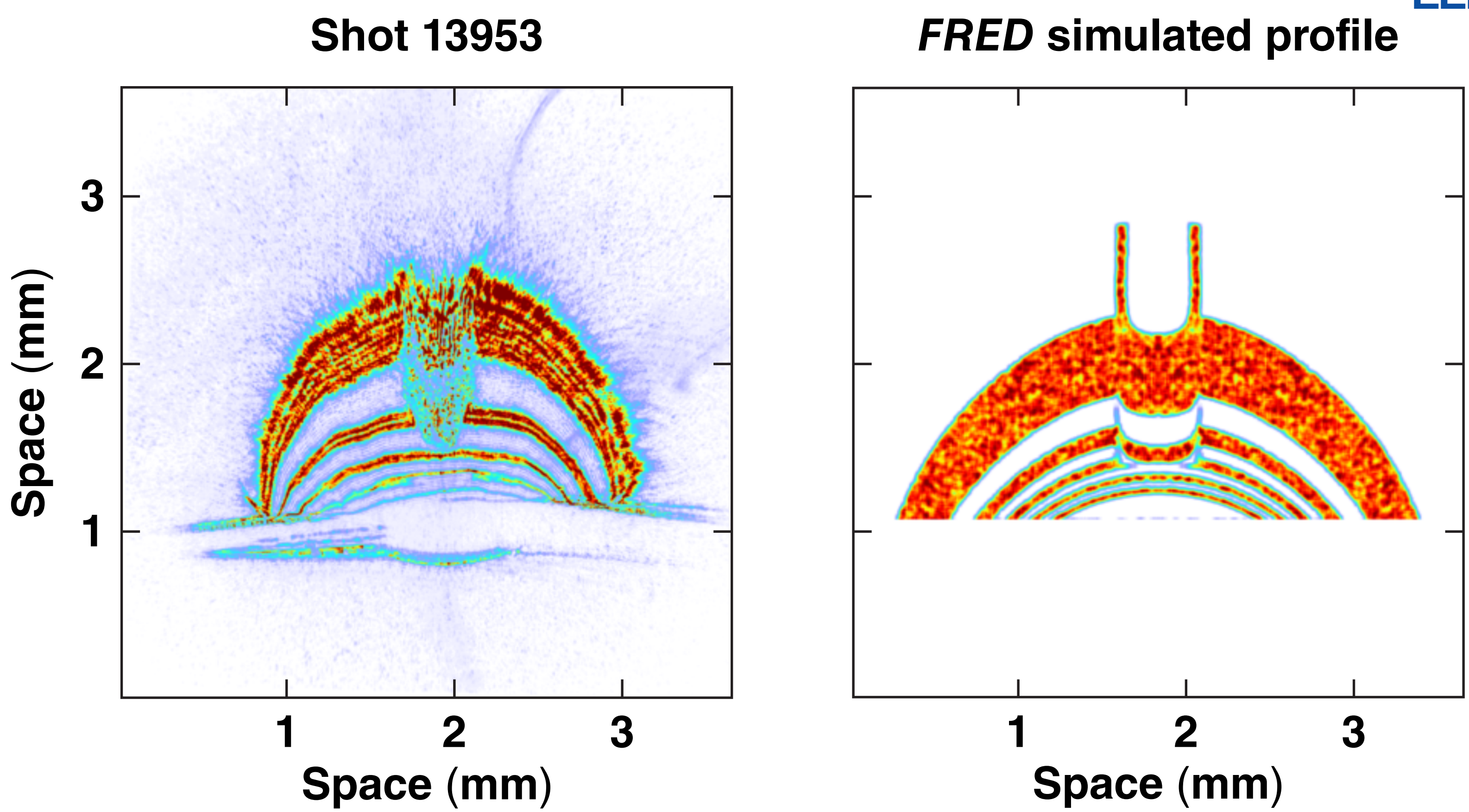


# The contours of the simulated ASF image are compared to the experimental image




**An iterative method of changing density profile to match the simulated image to the experimental image is under development.**

# *FRED* was used to model sharp density gradients produced by the channeling of a high-power picosecond beam




**The channel is characterized by matching the penetration depth, scale length, and residual plasma density in the channel.**

E21948

Courtesy of S. Ivanic

Summary/Conclusions

# The 4$\omega$ diagnostic on OMEGA EP has been activated and is ready for use by external users

UR LLE

- A 10-ps, 20-mJ, 4$\omega$ probe laser is installed and in use on the OMEGA EP target chamber
- An *f*/4 system provides access to high-density, large-scale-length laser-produced plasmas
- The system was designed for advanced optical diagnostics
  - refractometry using angular spectral filters (ASF) (in use)
  - schlieren and shadowgraphy (in use)
  - grid imaging refractometry (future)
  - interferometry (future)
  - polarimetry (future)
- Advanced optical design tools are being developed to provide synthetic diagnostic images for experimental setup and analysis

**The diagnostics coupled with detailed optical modeling of the system provide a novel diagnostic platform for detailed plasma measurements.**

E21929