Understanding the Creation of NIF-Scale Plasmas at the Omega Laser Facility for Laser–Plasma Instability Studies

S. X. Hu, D. H. Edgell, D. H. Froula, V. N. Goncharov, D. T. Michel
J. F. Myatt, S. Skupsky, and B. Yaakobi

University of Rochester, Laboratory for Laser Energetics

Summary

Hydro-calculated laser-intensity scalings for producing NIF-scale plasmas on OMEGA have been confirmed by experiments and self-simlilar model predictions

- The hydro-conditions of National Ignition Facility (NIF)-scale plasmas at the quarter-critical density regime are important for understanding laser–plasma instabilities (LPI's)
- A self-similar model for *LPI* experiments on OMEGA predicts at $n_c/4$ that
  - L_n (μm) $\propto I^{1/4}$
  - T_e (keV) $\propto I^{1/2}$
  - $I_{qc} \propto I$
- These predictions are reproduced by 2-D hydro simulations
- *DRACO* simulations further indicated that scale-length plasmas of L_n ~ 500 μm can be created with concave spherical half-shells

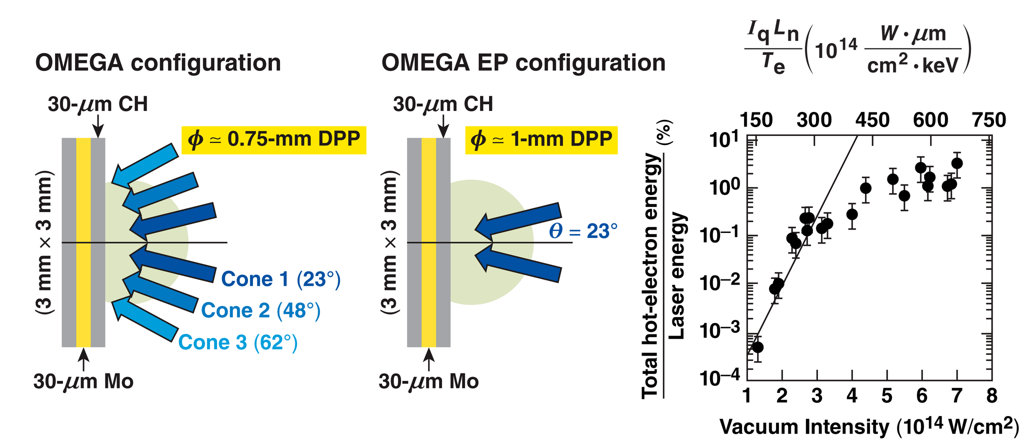
TC10609

Understanding and mitigating two-plasmon–decay (TPD) instability relies on the accurate knowledge of plasma conditions at $n_c/4$

- Long-scale-length plasmas (L_n > 400 μm), which favor TPD-instability growth, can be encountered in direct-drive–ignition implosions on the NIF
- To understand the laser-intensity scaling of TPD-induced fast electrons, it is crucial to know the exact plasma conditions (L_n, T_e, I_{qc}) at the quarter-critical density
- Benchmarking the hydro-simulated plasma conditions at $n_c/4$ with measurements and model analyses provide more confidence in the TPD-instability studies

TC10610

Long-scale-length plasma experiments with planar CH targets have been performed at the Omega Laser Facility using different distributed phase plates (DPP's)*

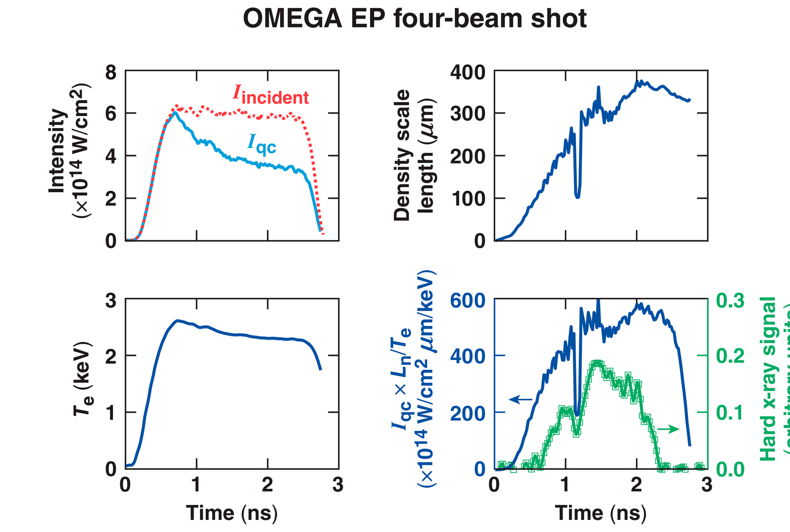


TC10437

*D. H. Froula *et al.*, Phys. Rev. Lett. 108, 165003 (2012).

Two-dimensional *DRACO* simulations* of these experiments provide the basic plasma conditions at $n_c/4$ to understand LPI

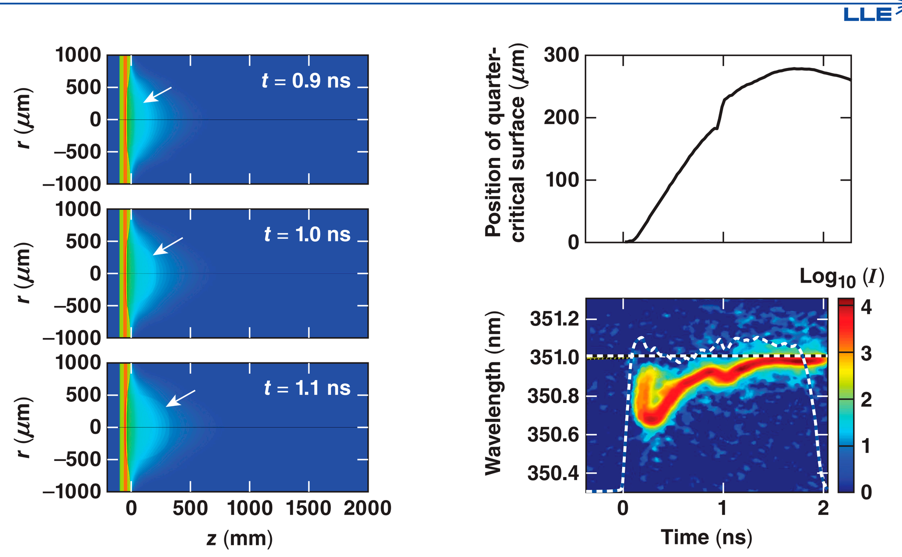
OMEGA EP four-beam shot



TC10441

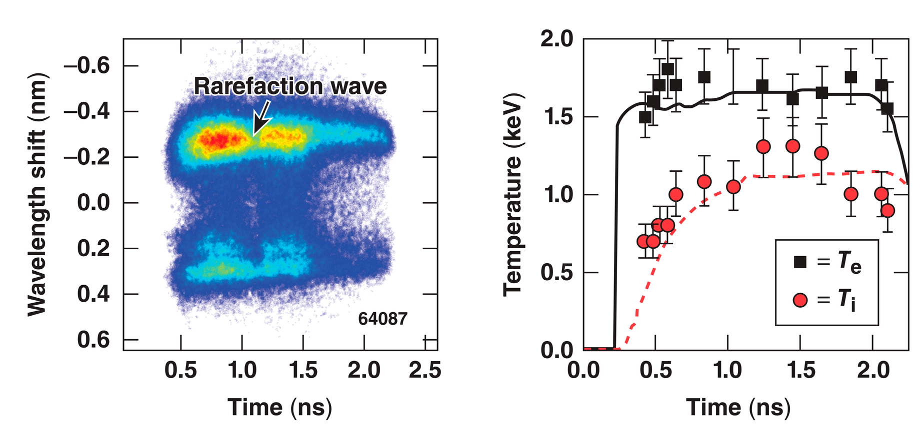
*S. X. Hu *et al.*, Phys. Plasmas 20, 032704 (2013).

The full-aperature backscatter station (FABS) measurement of light reflection by the rarefaction wave benchmarks the *DRACO*-predicted hydrodynamics of coronal plasmas



TC10613

The Thomson-scattering measurement of the electron temperature at $n_c/4$ showed good agreement with hydro simulations



TC10442

The self-similar model* is used to understand the laser-ablated slab plasma formation

- Solving the hydrodynamic equation with the self-similar dimensionless coordinate ξ

$$\begin{cases} v(m,t) = q_0^{-1/4}(k_0 t)^{3/8} V(\xi) \\ u(m,t) = q_0^{1/4}(k_0 t)^{1/8} U(\xi) \\ p(m,t) = q_0^{3/4}(k_0 t)^{-1/8} P(\xi) \\ e(m,t) = q_0^{1/2}(k_0 t)^{1/4} E(\xi) \\ q(m,t) = q_0 Q(\xi) \end{cases}$$

*S. Atzeni and J. Meyer-ter-Vehn, *The Physics of Inertial Fusion: Beam Plasma Interaction, Hydrodynamics, Hot Dense Matter, International Series of Monographs on Physics* (Clarendon Press, Oxford, 2004).

TC10615

The laser-intensity scaling of L_n, T_e, and I_{qc} can be derived from the self-similar model solutions

- The definition of L_n and the equation-of-state (EOS) relationship of e ~ kT_e

$$L_n = \frac{\rho}{|d\rho/dz|} = \rho \Big/ \left|\rho\frac{d\rho}{dm}\right| = 1 \Big/ \left|\frac{d\rho}{dm}\right| = 1 \Big/ \left|\frac{d\rho}{d\xi}\cdot\frac{d\xi}{dm}\right|.$$

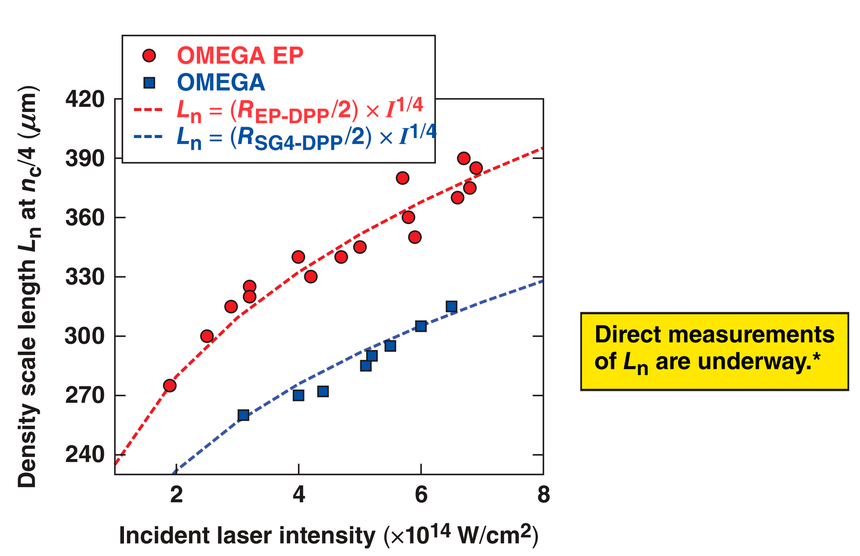
$L_n \propto I^{1/4}\lambda_0^{1/4}\cdot$

$T_e \propto I^{1/2}\lambda_0^{2}\cdot$

$I_{qc} \propto I$

TC10616

DRACO-simulated intensity scaling of L_n is in very good agreement with the self-similar model prediction



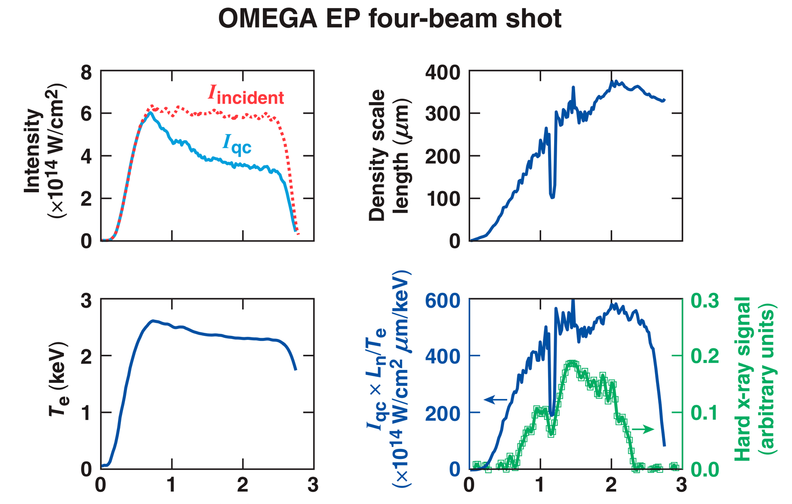
Direct measurements of L_n are underway.*

TC10443

*D. Haberberger, this conference.

Two-dimensional *DRACO* simulations* of these experiments provide the basic plasma conditions at $n_c/4$ to understand LPI

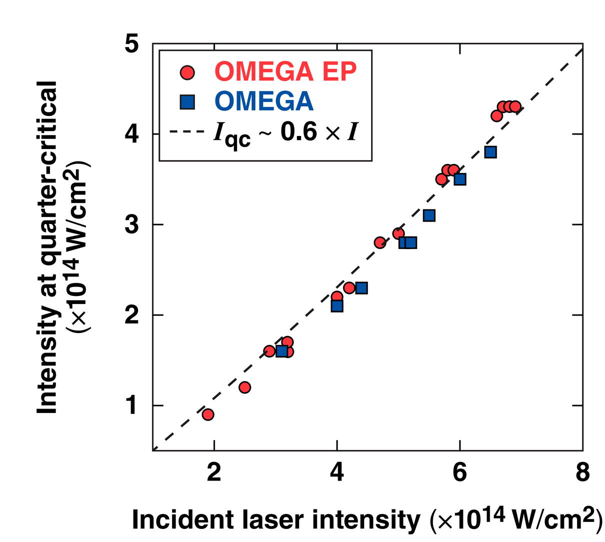
OMEGA EP four-beam shot



TC10441

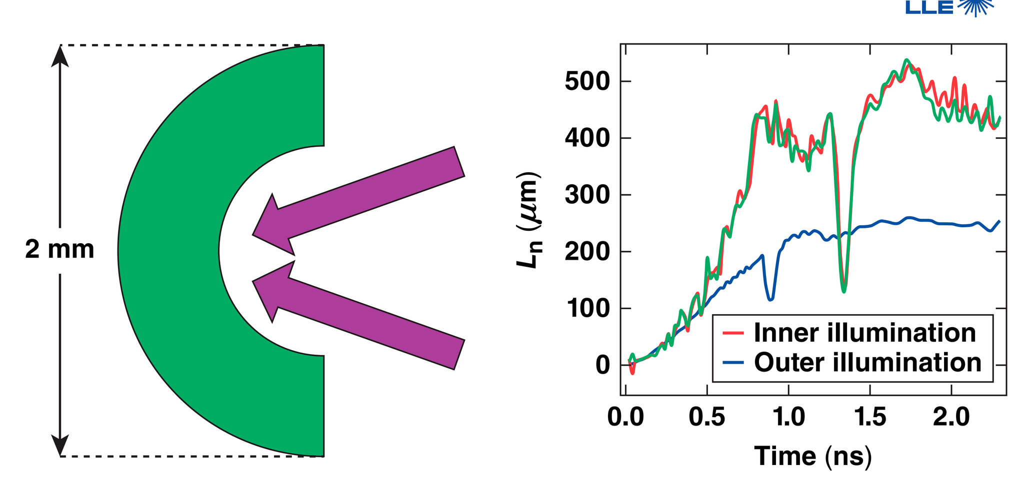
*S. X. Hu *et al.*, Phys. Plasmas 20, 032704 (2013).

Both *DRACO* simulations and the self-similar model predict the linear scaling of I_{qc} with the incident intensity



TC10619

With concave spherical half-shells, *DRACO* simulations predicted NIF-scale plasmas with even longer density scale lengths (L_n ~ 500 μm)



Measurements showed ~3× higher hard x-ray signals for concave targets with inner illumination than outer illumination at the same intensity.

TC10620

Summary

Hydro-calculated laser-intensity scalings for producing NIF-scale plasmas on OMEGA have been confirmed by experiments and self-simlilar model predictions

- The hydro-conditions of National Ignition Facility (NIF)-scale plasmas at the quarter-critical density regime are important for understanding laser–plasma instabilities (LPI's)
- A self-similar model for *LPI* experiments on OMEGA predicts at $n_c/4$ that
  - L_n (μm) $\propto I^{1/4}$
  - T_e (keV) $\propto I^{1/2}$
  - $I_{qc} \propto I$
- These predictions are reproduced by 2-D hydro simulations
- *DRACO* simulations further indicated that scale-length plasmas of $L_n \sim 500$ μm can be created with concave spherical half-shells

TC10609

Collaborators

D. H. Edgell, D. H. Froula, V. N. Goncharov, D. T. Michel
J. F. Myatt, S. Skupsky, and B. Yaakobi

University of Rochester
Laboratory for Laser Energetics

Understanding and mitigating two-plasmon–decay (TPD) instability relies on the accurate knowledge of plasma conditions at $n_c/4$

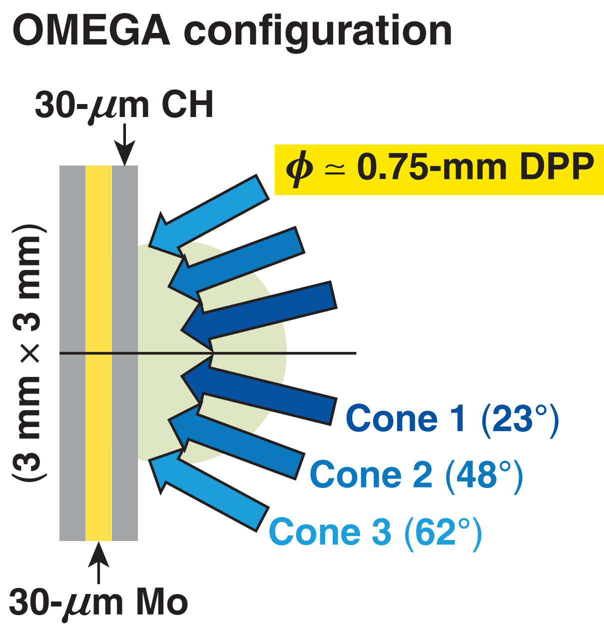
UR LLE

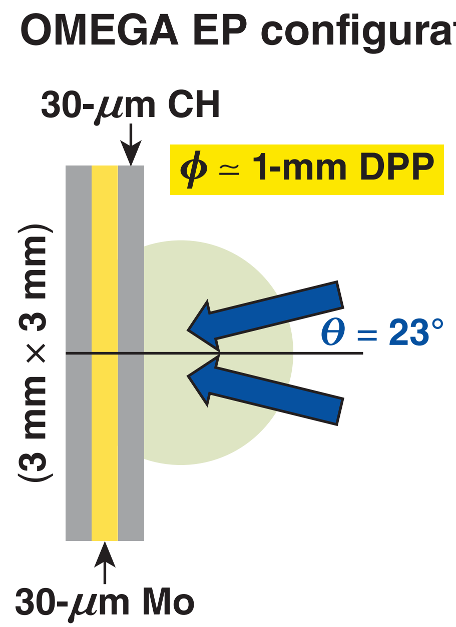
- Long-scale-length plasmas ($L_n > 400\ \mu m$), which favor TPD-instability growth, can be encountered in direct-drive–ignition implosions on the NIF

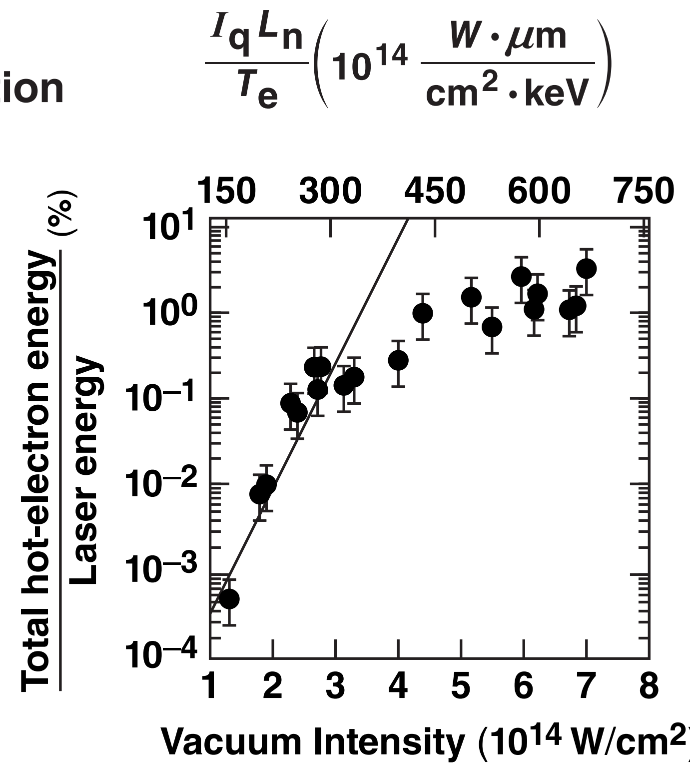
- To understand the laser-intensity scaling of TPD-induced fast electrons, it is crucial to know the exact plasma conditions (L_n, T_e, I_{qc}) at the quarter-critical density

- Benchmarking the hydro-simulated plasma conditions at $n_c/4$ with measurements and model analyses provide more confidence in the TPD-instability studies

Long-scale-length plasma experiments with planar CH targets have been performed at the Omega Laser Facility using different distributed phase plates (DPP's)*





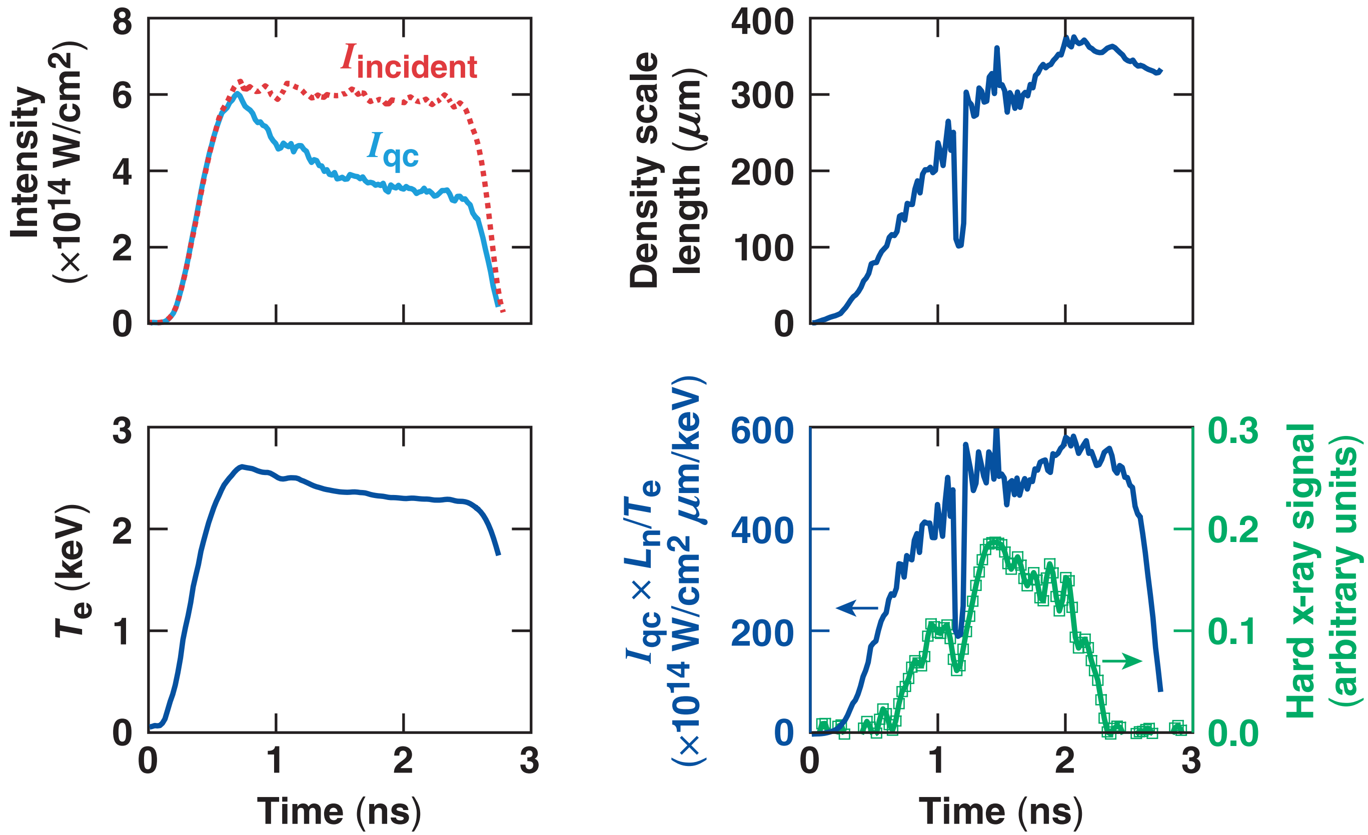


TC10437

*D. H. Froula *et al*., Phys. Rev. Lett. 108, 165003 (2012).

Two-dimensional *DRACO* simulations* of these experiments provide the basic plasma conditions at $n_c/4$ to understand LPI

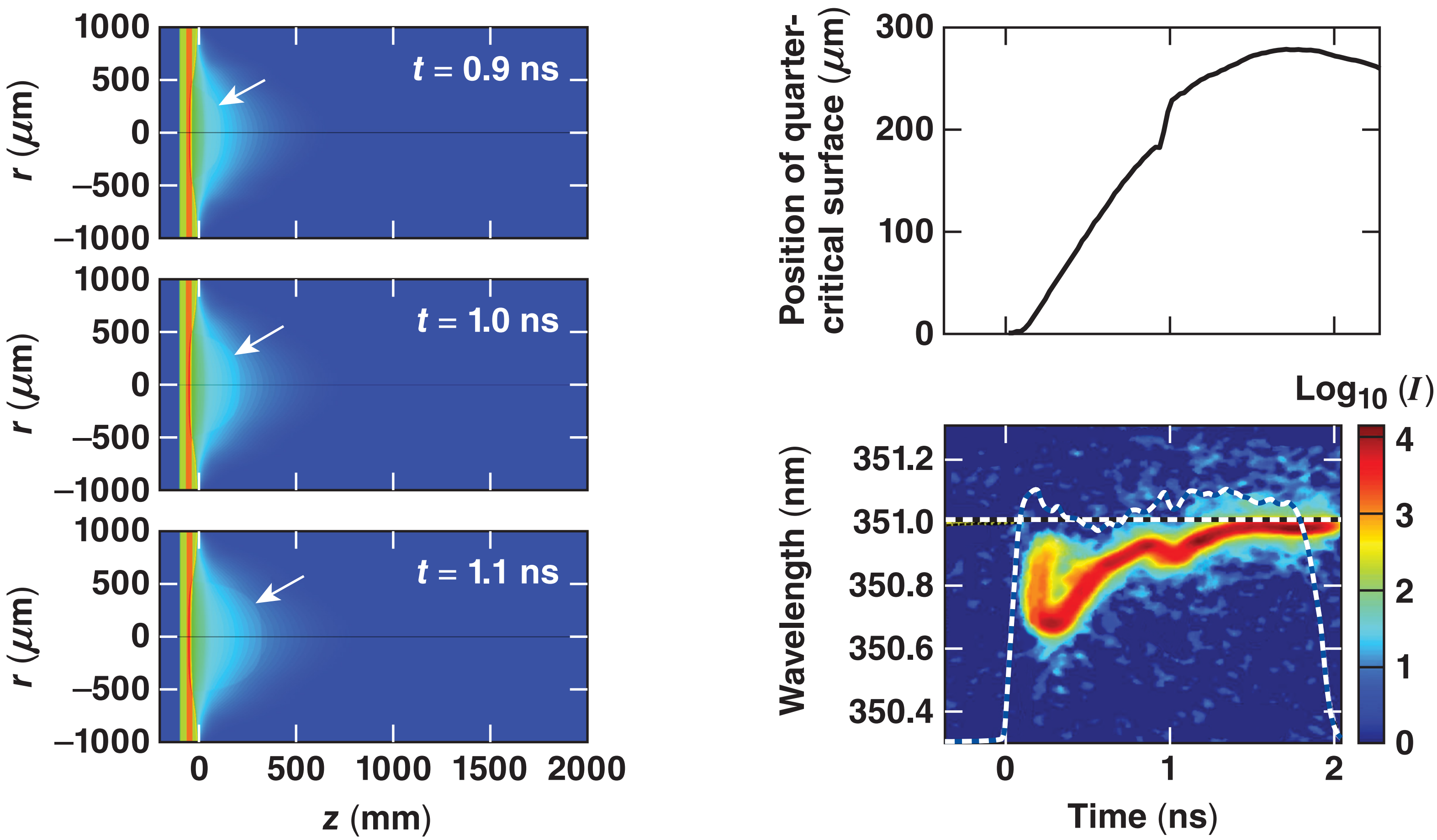
OMEGA EP four-beam shot



TC10441

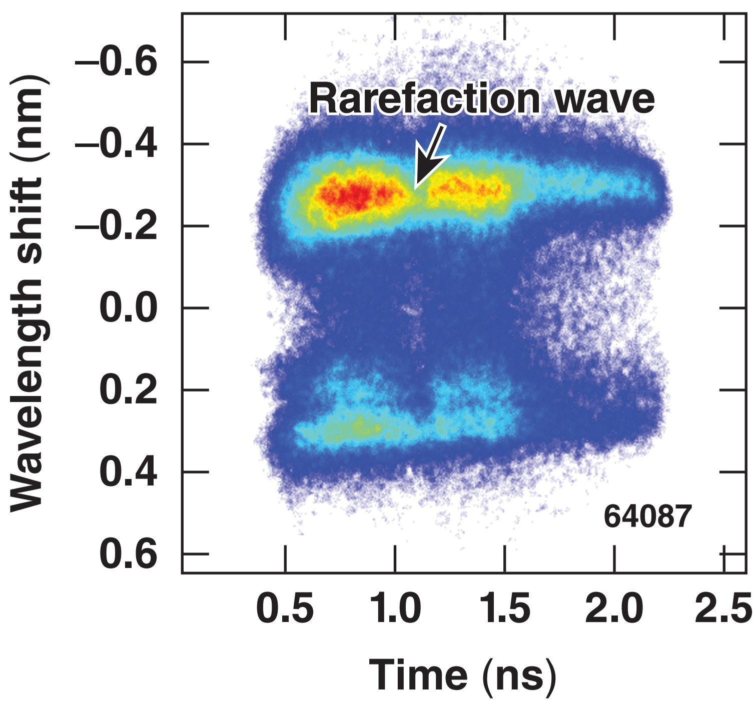
*S. X. Hu *et al*., Phys. Plasmas 20, 032704 (2013).

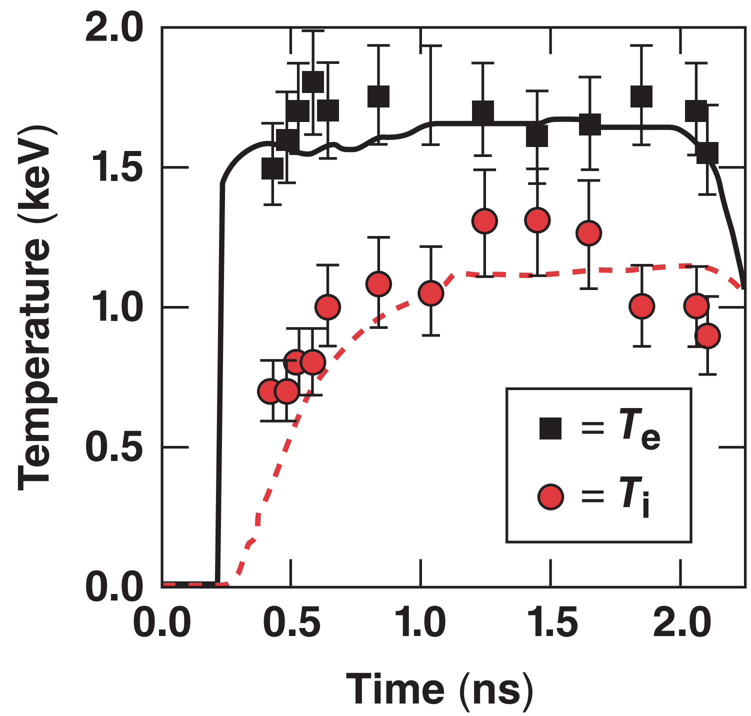
The full-aperature backscatter station (FABS) measurement of light reflection by the rarefaction wave benchmarks the *DRACO*-predicted hydrodynamics of coronal plasmas



TC10613

The Thomson-scattering measurement of the electron temperature at $n_c/4$ showed good agreement with hydro simulations





The self-similar model* is used to understand the laser-ablated slab plasma formation

- Solving the hydrodynamic equation with the self-similar dimensionless coordinate ξ

$$
\begin{cases}
v(m,t) = q_0^{-1/4}(k_0 t)^{3/8} V(\xi) \\
u(m,t) = q_0^{1/4}(k_0 t)^{1/8} U(\xi) \\
p(m,t) = q_0^{3/4}(k_0 t)^{-1/8} P(\xi) \\
e(m,t) = q_0^{1/2}(k_0 t)^{1/4} E(\xi) \\
q(m,t) = q_0 Q(\xi)
\end{cases}
$$

*S. Atzeni and J. Meyer-ter-Vehn, *The Physics of Inertial Fusion: Beam Plasma Interaction, Hydrodynamics, Hot Dense Matter, International Series of Monographs on Physics* (Clarendon Press, Oxford, 2004).

The laser-intensity scaling of L_n, T_e, and I_{qc} can be derived from the self-similar model solutions

- The definition of L_n and the equation-of-state (EOS) relationship of $e \sim kT_e$

$$L_n = \frac{\rho}{\left| d\rho/dz \right|} = \rho \Big/ \left| \rho \frac{d\rho}{dm} \right| = 1 \Big/ \left| \frac{d\rho}{dm} \right| = 1 \Big/ \left| \frac{d\rho}{d\xi} \cdot \frac{d\xi}{dm} \right| .$$

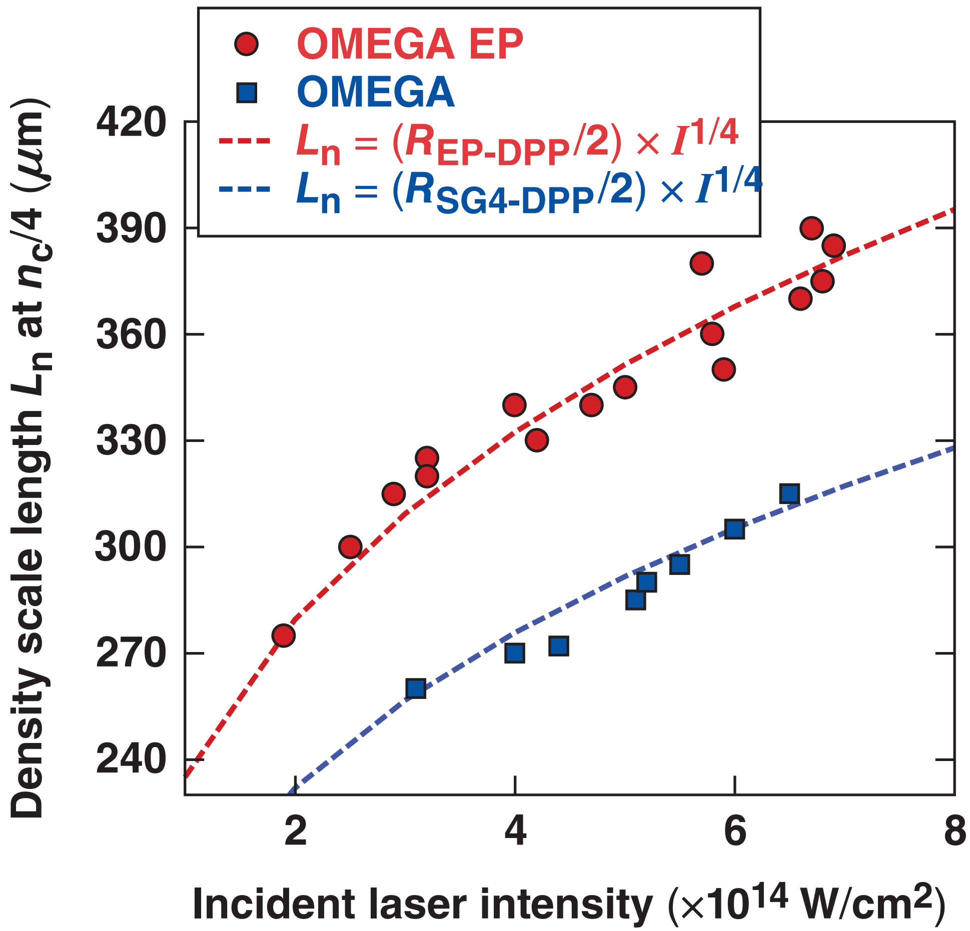
$$L_n \propto I^{1/4} \lambda_0^{1/4} .$$

$$T_e \propto I^{1/2} \lambda_0^{2} .$$

$$I_{qc} \propto I$$

TC10616

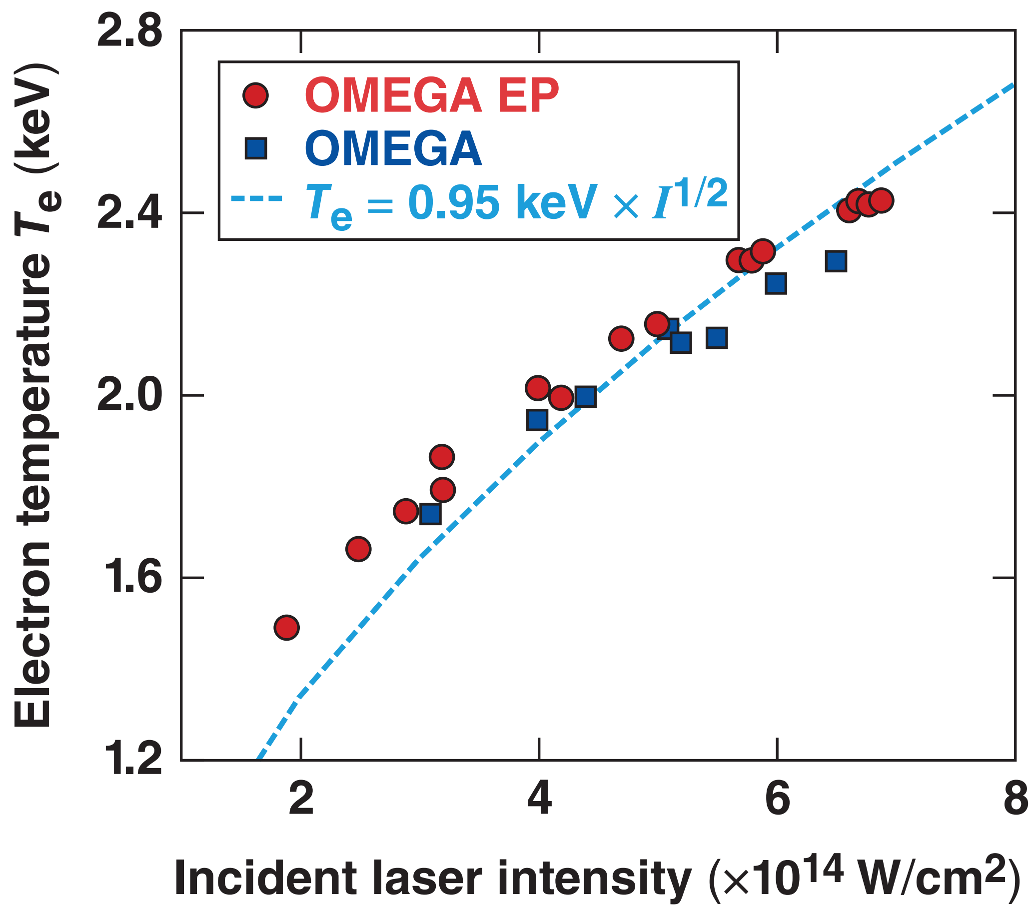
DRACO-simulated intensity scaling of L_n is in very good agreement with the self-similar model prediction



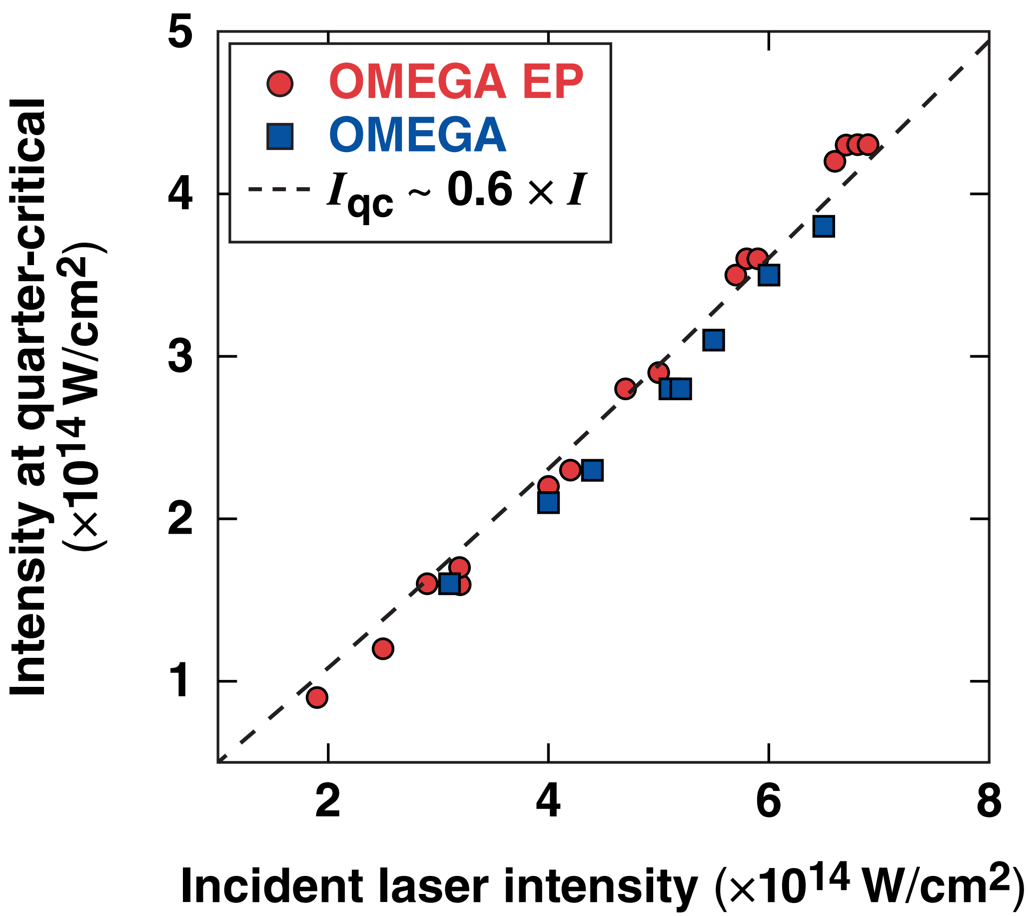
Direct measurements of L_n are underway.*

*D. Haberberger, this conference.

DRACO-simulated intensity scaling of T_e agrees with the self-similar model prediction

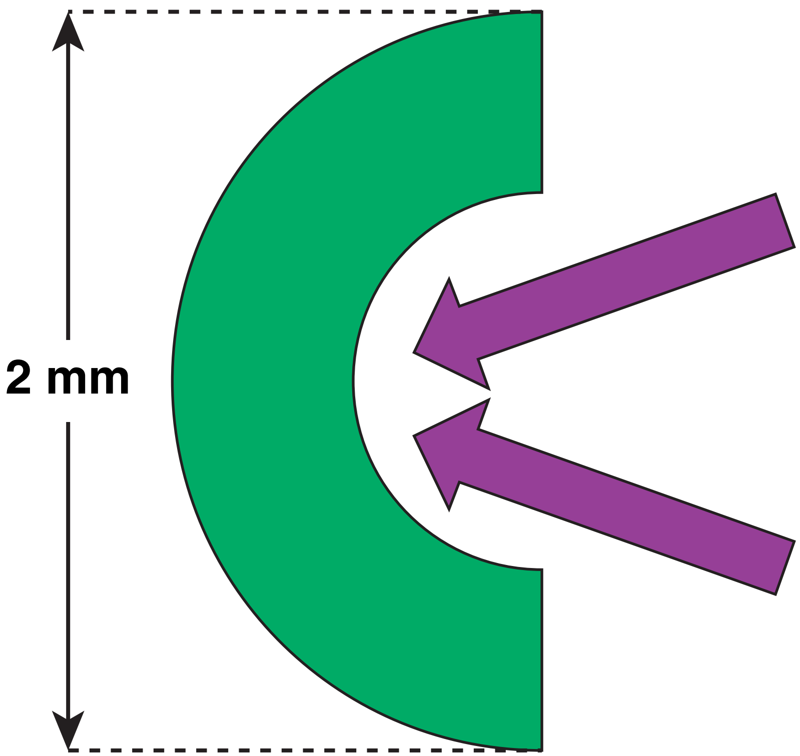


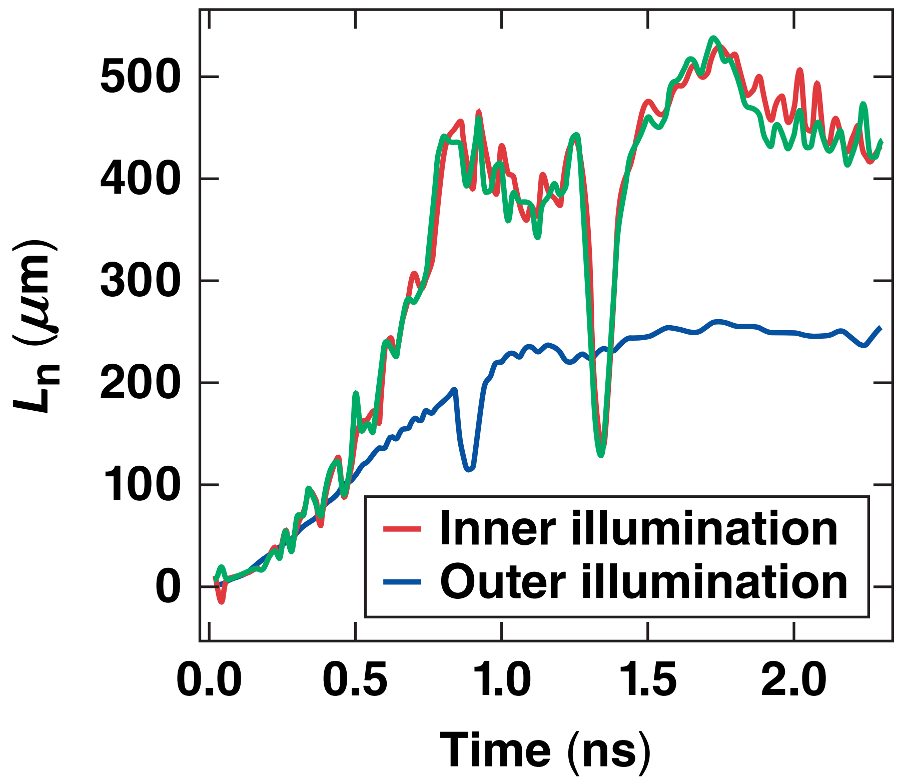
Both *DRACO* simulations and the self-similar model predict the linear scaling of I_{qc} with the incident intensity



TC10619

With concave spherical half-shells, *DRACO* simulations predicted NIF-scale plasmas with even longer density scale lengths (L_n ~ 500 μm)





Measurements showed ~3× higher hard x-ray signals for concave targets with inner illumination than outer illumination at the same intensity.

TC10620

Summary/Conclusions

Hydro-predicted laser-intensity scalings for producing NIF-scale plasmas on OMEGA have been confirmed by experiments and model predictions

- **The hydro-conditions of National Ignition Facility (NIF)-scale plasmas at the quarter-critical density regime are important for understanding laser–plasma instabilities (LPI's)**
- **A self-similar model for *LPI* experiments on OMEGA predicts at $n_c/4$ that**
  - L_n (μm) $\propto I^{1/4}$
  - T_e (keV) $\propto I^{1/2}$
  - $I_{qc} \propto I$
- **These predictions are reproduced by 2-D hydro simulations**
- ***DRACO* simulations further indicated that scale-length plasmas of $L_n \sim 500$ μm can be created with concave spherical half-shells**