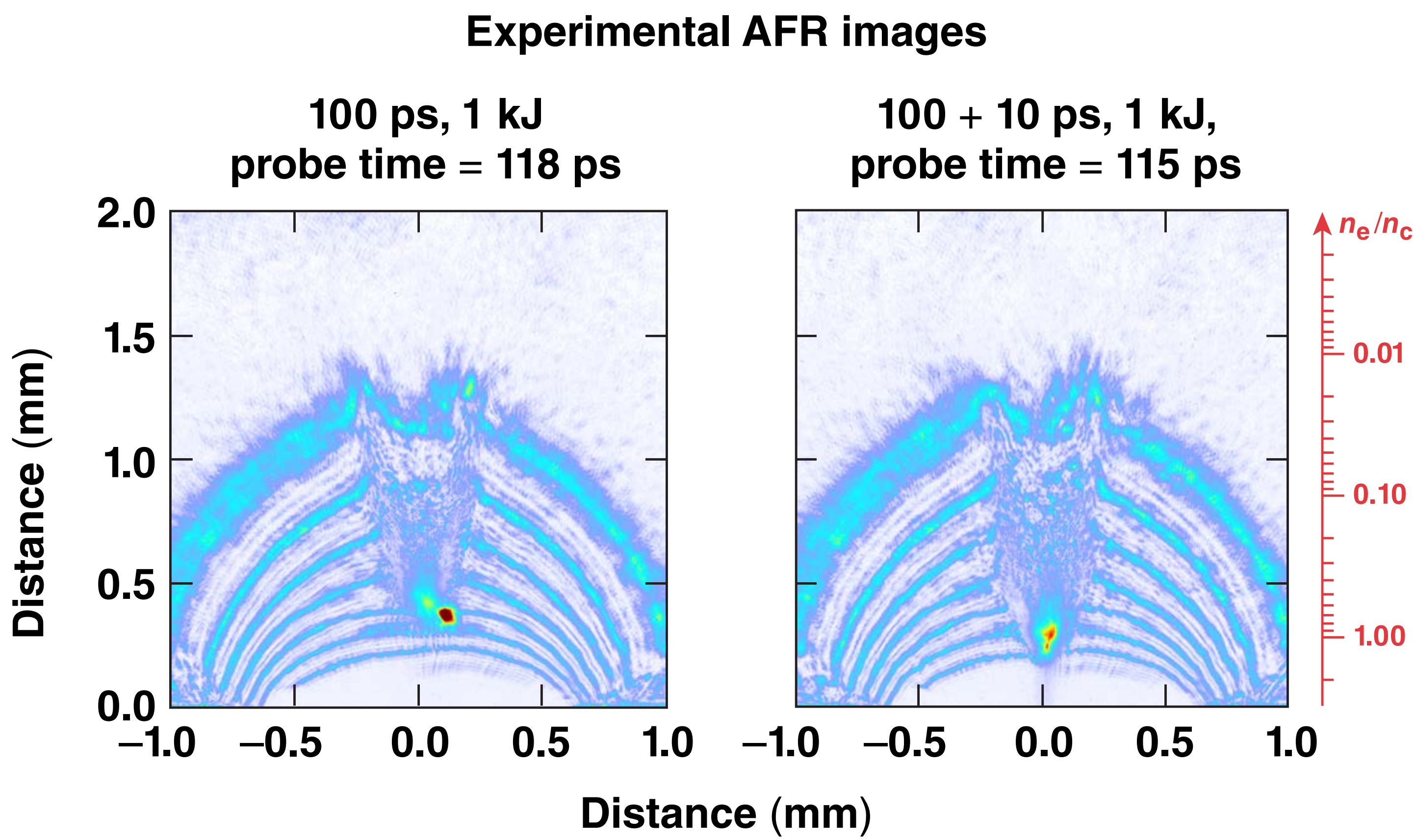
# Optical Probing of Laser-Channeling Experiments on the OMEGA EP Laser System

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56th Annual Meeting of the
American Physical Society
Division of Plasma Physics
New Orleans, LA
27–31 October 2014

Summary

# OMEGA EP experiments demonstrate the creation of a channel to overcritical densities in a long-scale-length plasma

UR LLE

- Angular filter refractometry (AFR) makes it possible to observe the density modification of a channel beyond critical density ($1.4 \times 10^{21}$ $cm^{-3}$)
- A high-intensity (>$10^{18}$ $W/cm^2$) laser evacuates a conical-shaped cavity with ~65% lower density than the background density
- A 100-ps, 1-kJ laser pulse produced a channel beyond critical, allowing for the efficient transmission of a high-intensity ($I \cong 4 \times 10^{19}$ $W/cm^2$) co-propagated pulse to beyond critical density

**These experiments show for the first time the guiding of a high-intensity pulse to beyond critical density in a fast-ignition (FI)-relevant (>1-keV, $L_s$ ~ 300-$\mu$m) plasma.**

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# Collaborators


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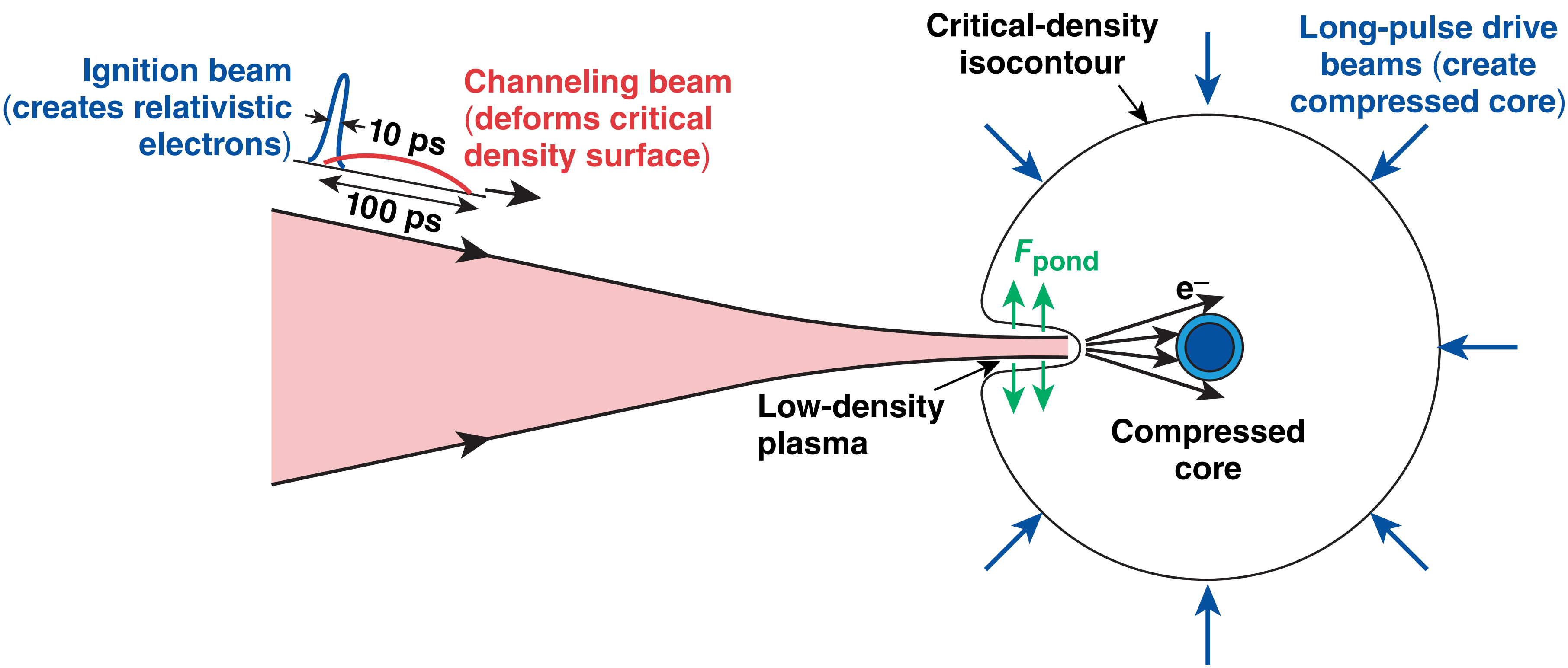
# Channeling through the corona of an imploded capsule offers an alternative to cone-in-shell targets



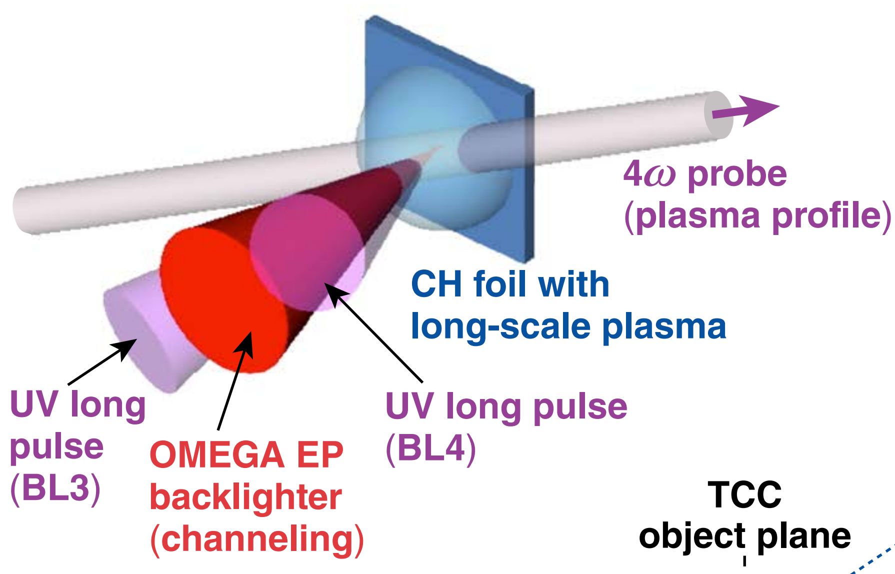
## Fast heating with ultra-intense laser beams*

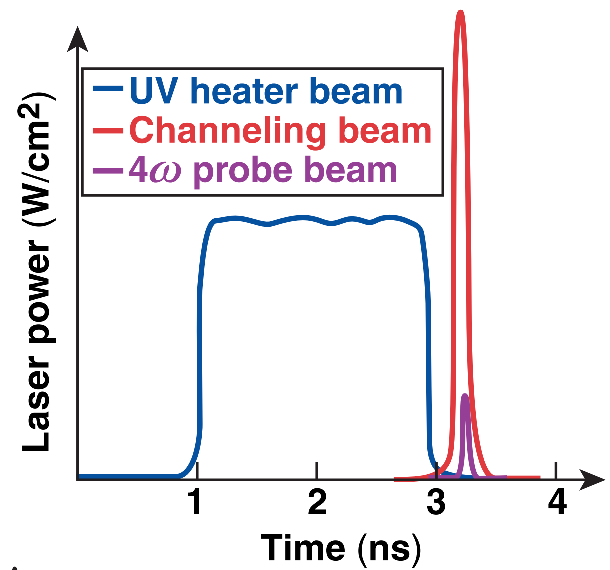


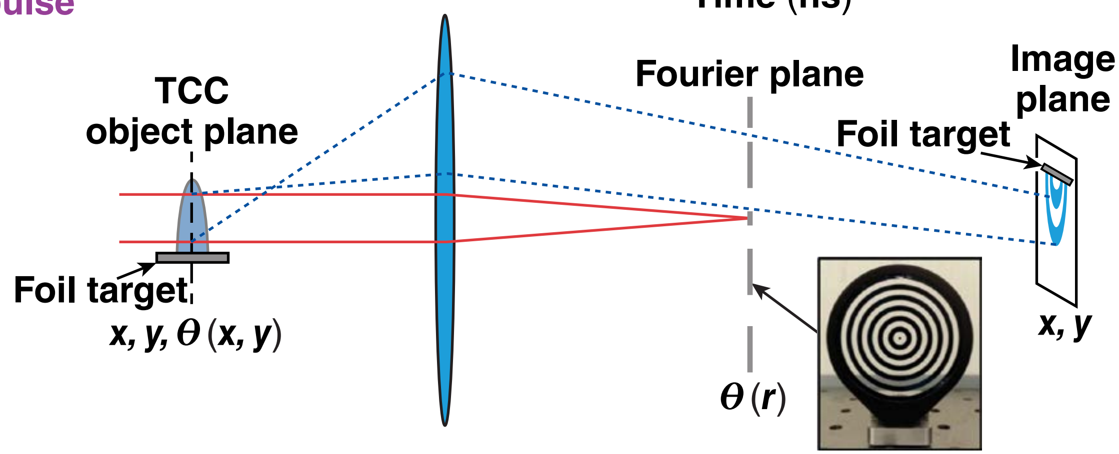

**The channeling beam evacuates the coronal plasma ahead of a second laser pulse used to heat the core of an imploded target.**

*M. Tabak *et al*., Phys. Plasmas 1, 1626 (1994).

# An experiment to measure channeling depth and residual density inside the channel was performed on OMEGA EP

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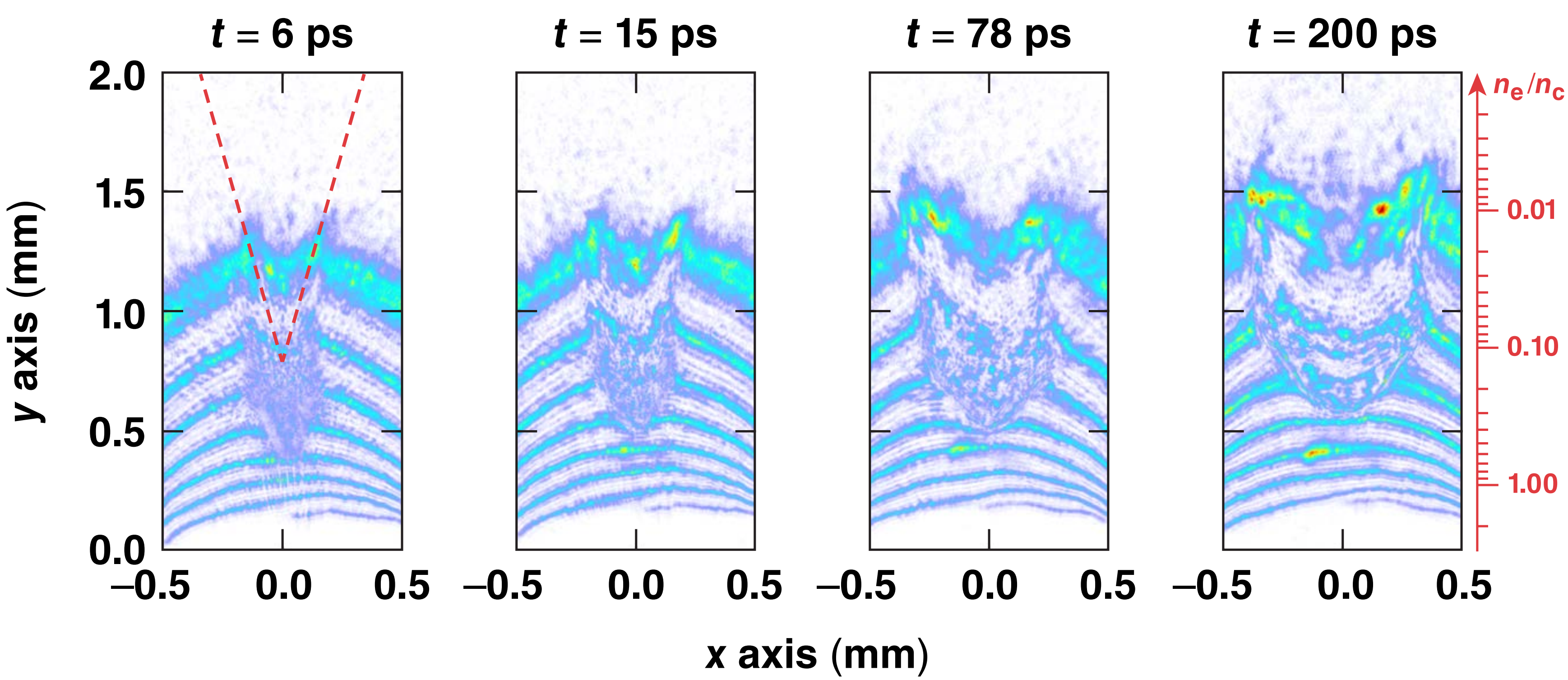
D. Haberberger *et al*., Phys. Plasmas 21, 056304 (2014).

# A single 10-ps, 1.2-kJ pulse channels up to ~0.6 $n_c$ through the underdense corona

Channeling beam: 10 ps, 1.2 kJ, 125 TW, $I \cong 4 \times 10^{19}$ W/cm$^2$

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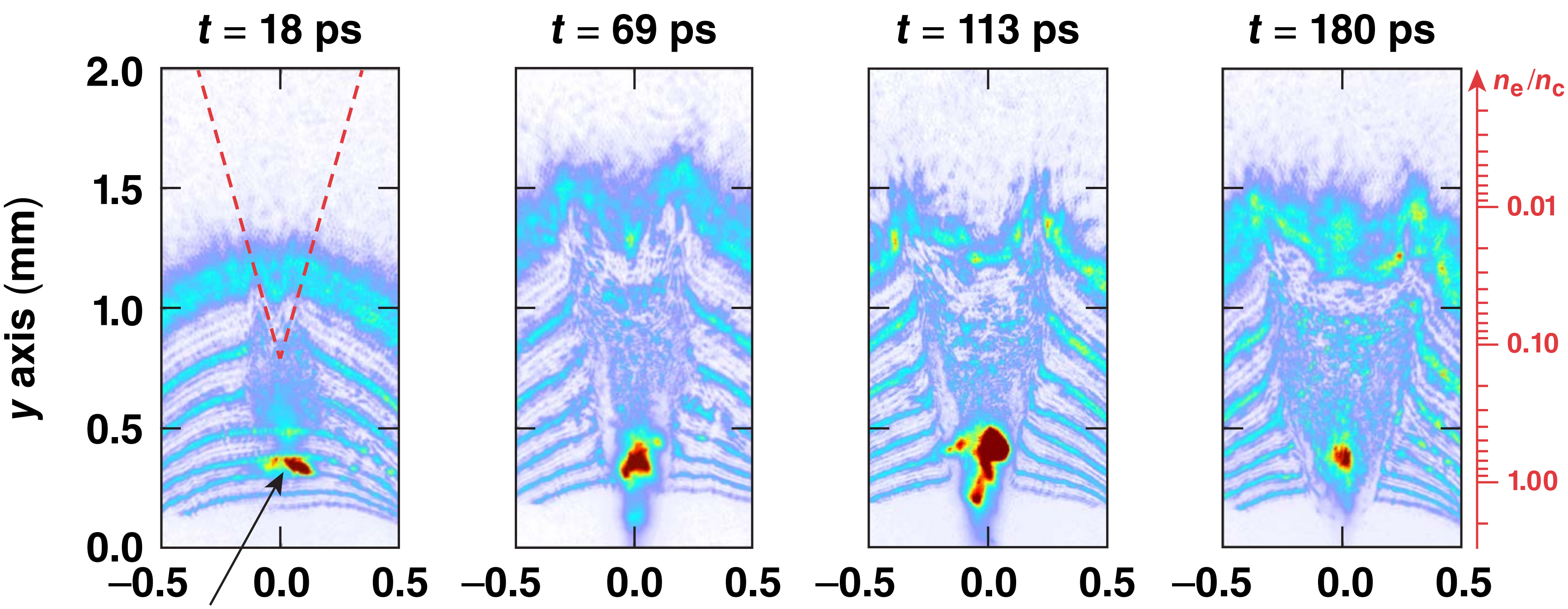
# A single 100-ps, 2-kJ pulse bores to overcritical densities in the corona

Channeling beam: 100 ps, 2 kJ, 20 TW, $I \cong 4 \times 10^{18}$ W/cm$^2$




Fourth-harmonic self-emmision from high-intensity laser

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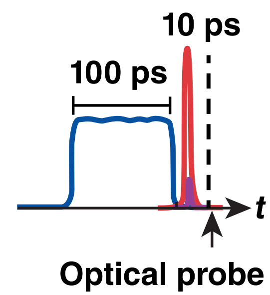
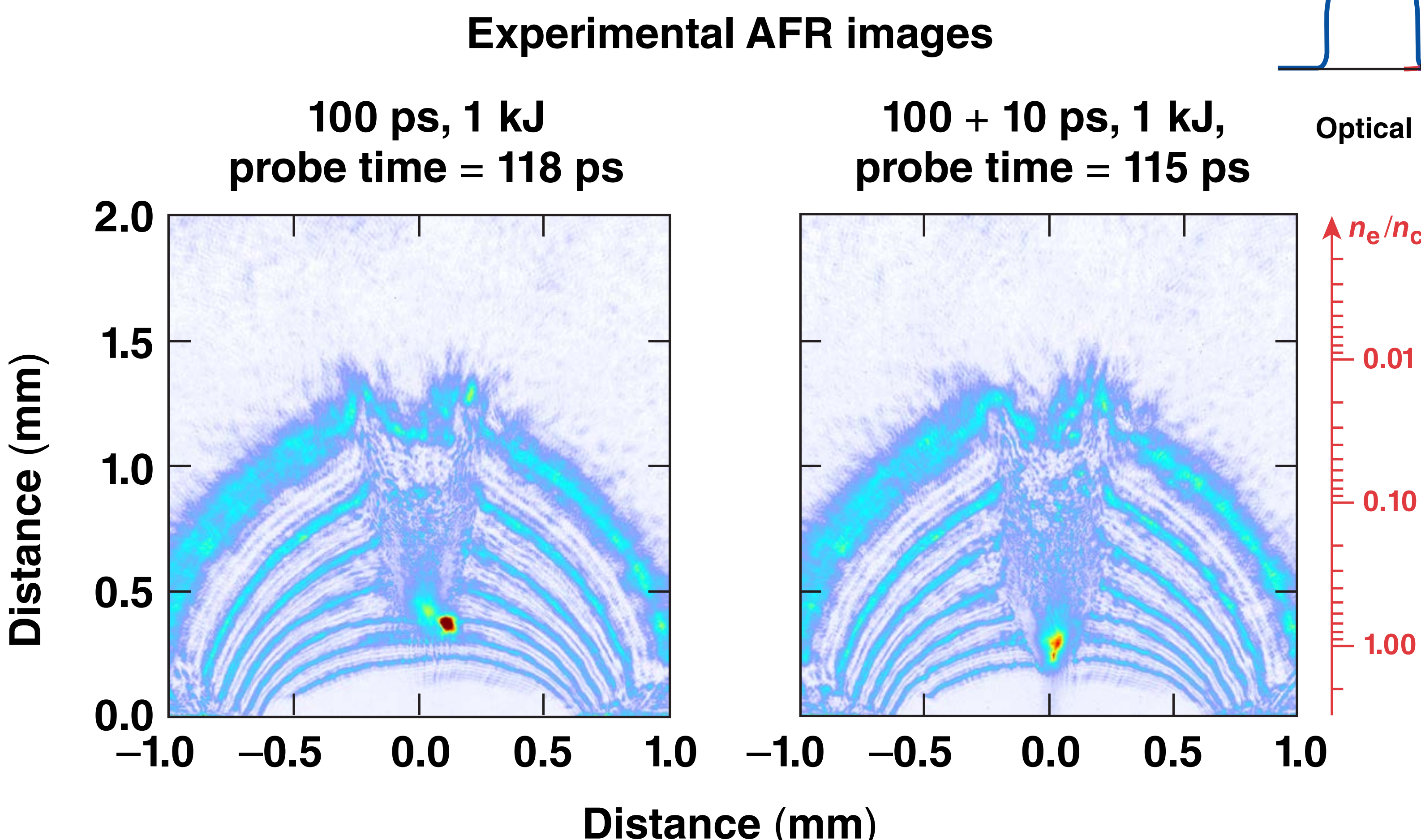
# Experiments with co-propagating 100-ps and 10-ps pulses were performed

- A shock-driven channel can be used to guide a second laser beam

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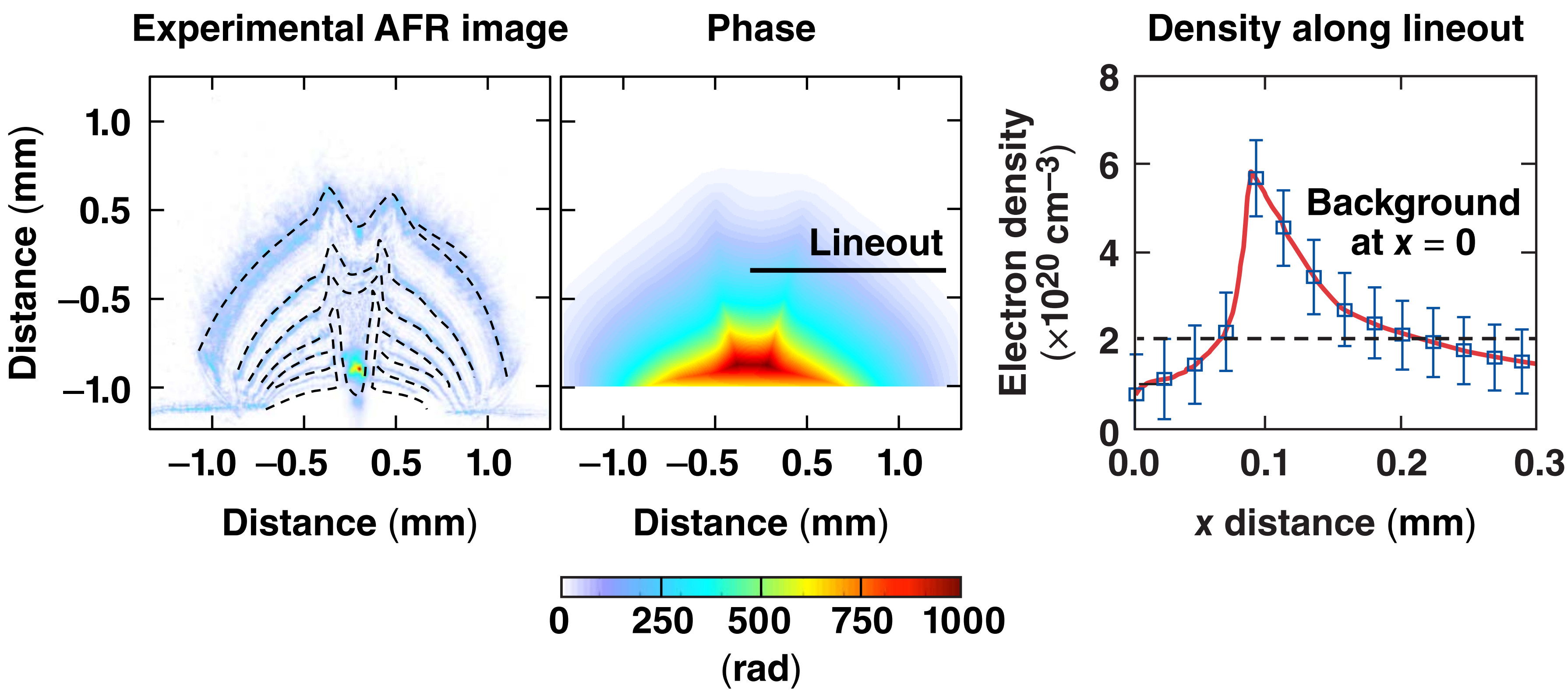
# The residual density in the channel is found through an Abel inversion of the AFR image




**The density in the channel is reduced to $(1 \pm 0.75) \times 10^{20}$ cm$^{-3}$.**

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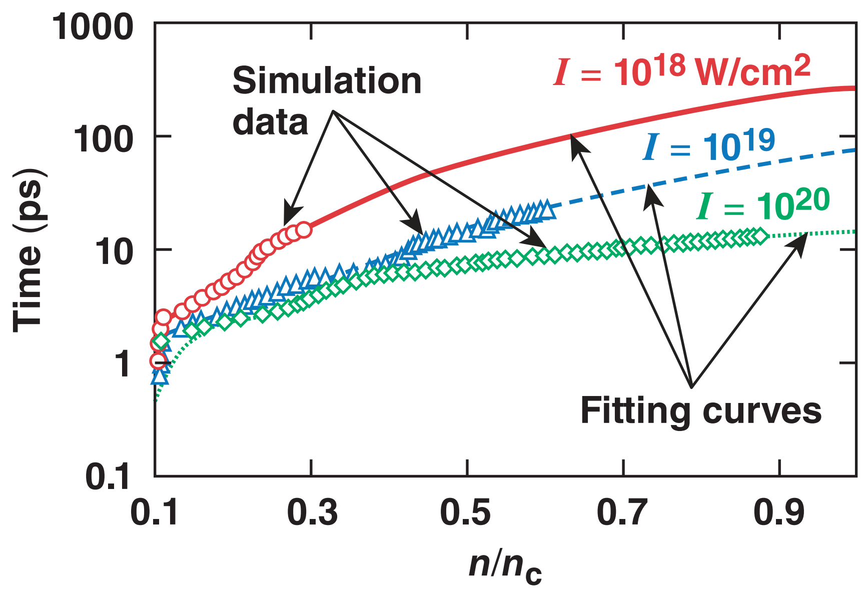
# The observed channel progression is consistent with particle-in-cell (PIC) simulations*




- Scaling laws for the required time and energy for channel to reach $n_c$**

$$T(\text{ps}) = 150\, I_{18}^{-0.64},\ E(\text{kJ}) = 0.85\, I_{18}^{-0.32}$$

$$2 \times 10^{18}\ \text{W/cm}^2\text{: 100 ps, 1 kJ; } 2 \times 10^{19}\ \text{W/cm}^2\text{: 15 ps, 2.2 kJ}$$

**The 100-ps pulse has sufficient energy to reach the critical density, while the 10-ps pulse lacks energy to reach the critical density.**

*G. Li *et al.*, Phys. Rev. Lett. 100, 125002 (2008).
**G. Li *et al.*, Phys. Plasmas 18, 042703 (2011).

Summary/Conclusions

# OMEGA EP experiments demonstrate the creation of a channel to overcritical densities in a long-scale-length plasma

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- Angular filter refractometry (AFR) makes it possible to observe the density modification of a channel beyond critical density ($1.4 \times 10^{21}$ cm$^{-3}$)
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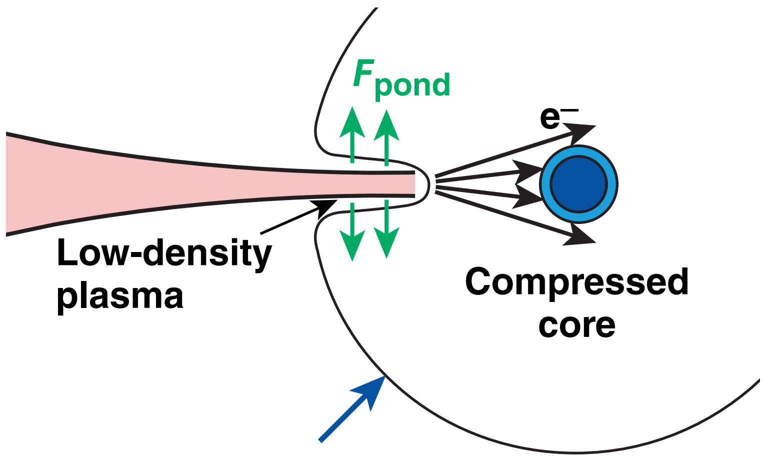
**These experiments show for the first time the guiding of a high-intensity pulse to beyond critical density in a fast-ignition (FI)-relevant (>1-keV, $L_s$ ~ 300-$\mu$m) plasma.**

# Using the intense light pressure of a second laser pulse, channeling may hold promise as an additional method of laser pulse delivery

- $P_L$ ~ 100's of Mbar
- A shock-prepared channel can act as an embedded fiber-optic cable to guide a second pulse*
- Preformed channels have been demonstrated to enhance the propagation of a trailing pulse**
- Laser-compressed matter has a halo of underdense low-density plasma "corona" that must be dealt with; the corona plasma has a density stratification length of 100's of microns

**Measurements**

- Forward-going velocity of the channel in an FI-relevant plasma ($T_e$ > 1 keV, $L_s$ ~ 300 $\mu$m)
- Density depletion inside the channel
- Duration of channel existence




**The channel must reach a comparable depth as the cone tip in cone-in-shell implosions.*****

*C. G. Durfee and H. M. Milchberg, Phys. Rev. Lett. 71, 2409 (1993).
**J. Fuchs *et al.*, Phys. Rev. Lett. 105, 225001 (2010).
***W. Theobald *et al.*, Phys. Plasmas 18, 056305 (2011).

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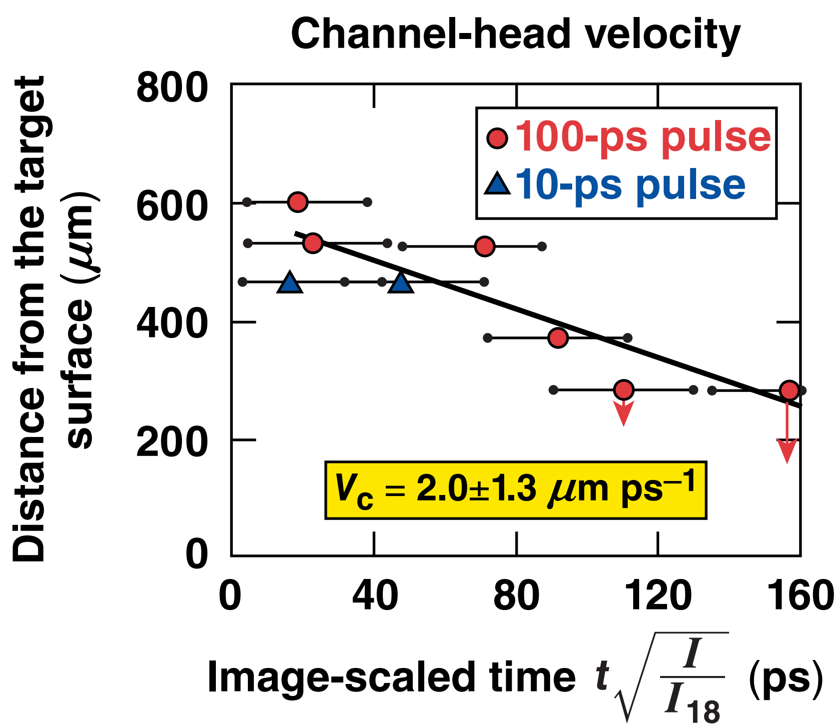
# The channel front advances at a supersonic velocity

UR LLE

- All shots are scaled by average intensity
- Error bars in timing (±20 ps) dominate the uncertainty in $V_c$
- Compares 1.25-kJ, 10-ps pulses with 0.75- to 2.6-kJ, 100-ps pulses
- This scaling shows the channeling beam is pushing against a reflective front in the entire underdense region




S. Ivancic in preparation.

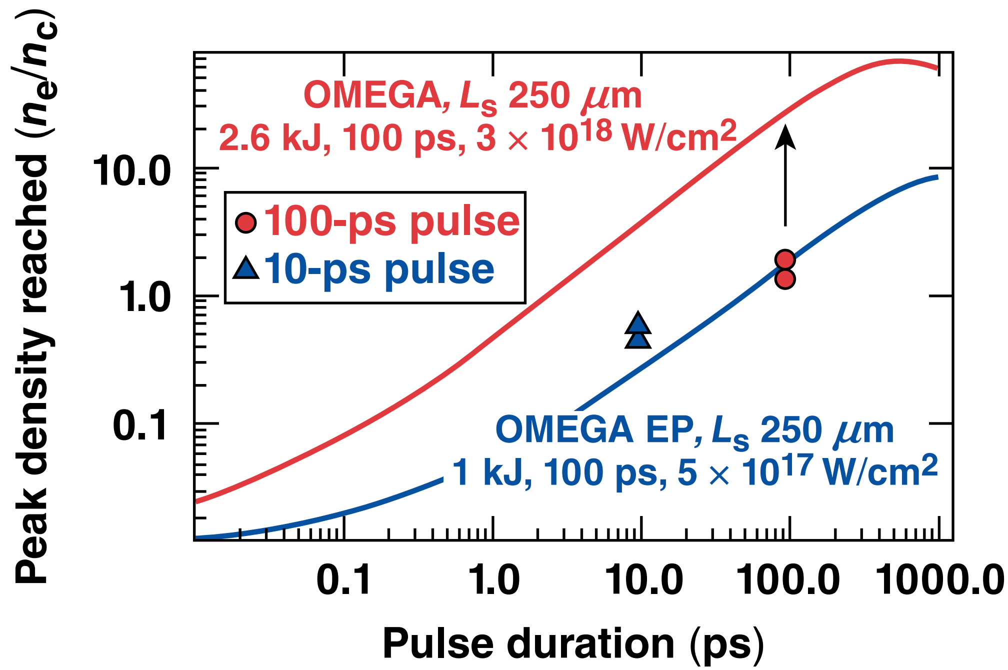
# A ponderomotive hole-boring model accurately describes the ultimate depth the channel reaches

$$d'(t) = \sqrt{\frac{IZ}{n_e \exp\left(-\frac{d}{L_s}\right) Mc}} - v_b$$

$$V_b = 0.3\ \mu m/ps$$

$$L_s = 250\ \mu m$$

- The model is based on a balance of velocities acting on the channel
- $V_c$ – channel-head velocity (measured)
- $V_b$ – blowoff velocity of corona (measured)



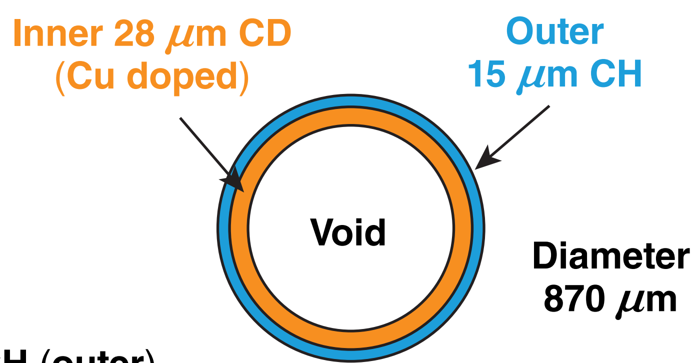

- The peak depth is a function of the channeling-beam duration and blowoff velocity

**This model suggests that a full-energy (2.6-kJ, 100-ps, 3 × $10^{18}$ W/cm$^2$) OMEGA EP beam may reach up to 25 $n_c$ in a shorter-scale-length OMEGA implosion ($L_s$ ~ 100 $\mu$m).**

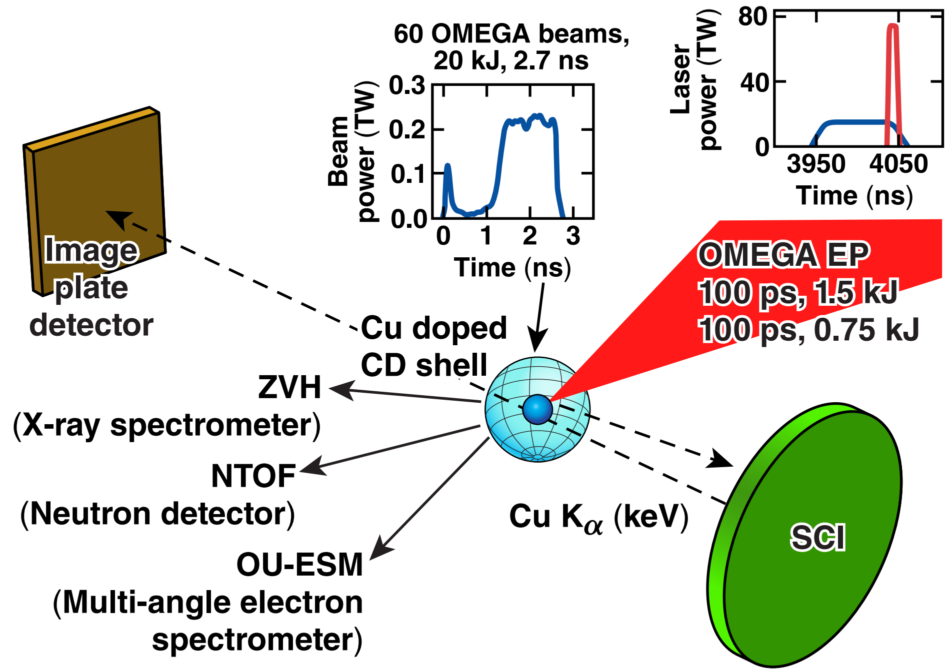
Integrated Experiment Proposal

# Laboratory Basic Science (LBS) shot time was allocated to study integrated channeling experiments on OMEGA

Target design:




CH (outer)
CD or Cu-doped (inner)



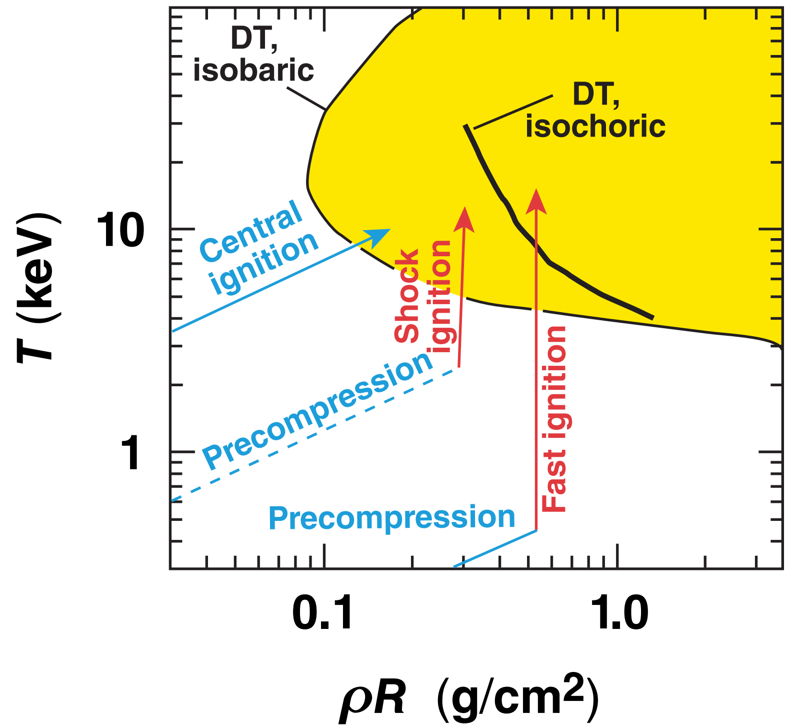

- The neutron yield from $D_2$ reactions gives a measure of the increase in temperature caused by the electron heating
- A spherical crystal imager* (SCI) is used to obtain a spatial distribution of Cu $K_\alpha$ x rays induced by fast electrons in the imploded core

*C. Stoeckl *et al*., Rev. Sci. Instrum. 83, 10E501 (2012).

# Isochoric-heated, laser-compressed targets have a practical application in fast ignition*



- **The ponderemotive potential of intense laser pulses (>$10^{18}$ W/$cm^2$) creates fast electrons in the MeV range****
- **Fast-electron heat-compressed material at a constant volume created dense and hot plasmas**




**A method is required to channel the intense laser through the large corona (~mm) of laser-compressed targets.**

*M. Tabak *et al*., Phys. Plasmas 1, 1626 (1994).
**S. C. Wilks *et al*., Phys. Rev. Lett. 69, 1383 (1992).