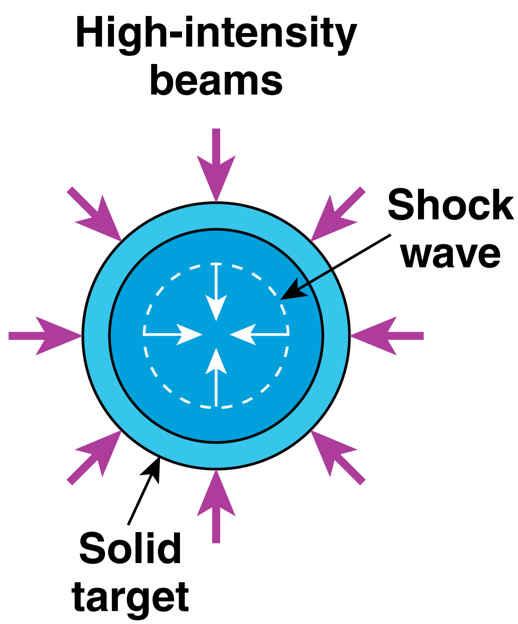
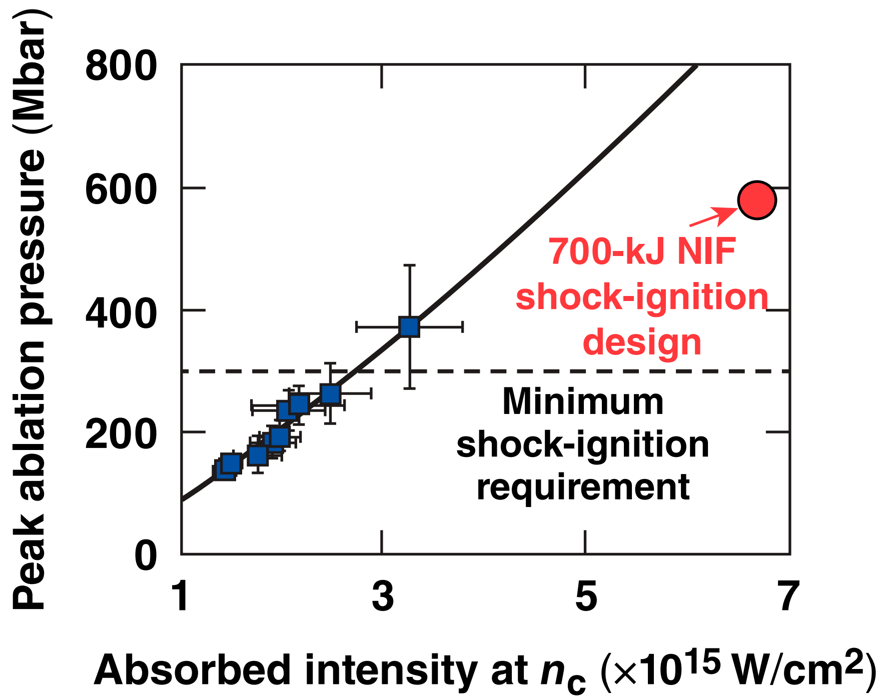
Spherical Strong-Shock Generation for Shock-Ignition Inertial Fusion





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Summary

The inferred ablation pressures from spherical strong-shock experiments exceed the 300 Mbar required for shock ignition

- Pressures are inferred from simulations of experiments studying the shock propagation in solid spheres
- Laser–plasma instabilities produce large amounts of hot electrons (T_{hot} < 100 keV), reaching up to ~9% of the laser energy at absorbed intensities of 3×10^{15} W/cm^2
- Moderate-energy hot electrons significantly enhance the pressure (up to 45%) and are beneficial to shock ignition
- Experiments are proposed at the National Ignition Facility (NIF) to study the generation of strong shocks with ignition-relevant density scale length

Collaborators

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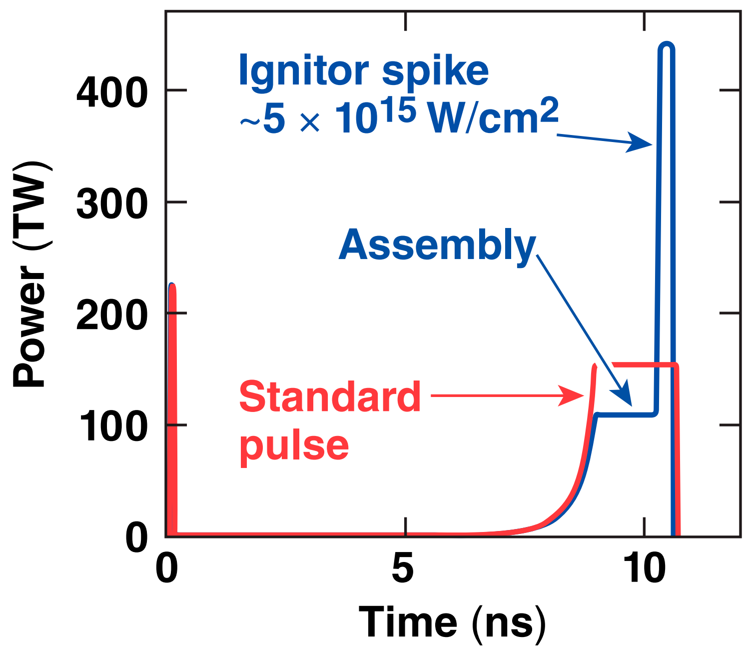
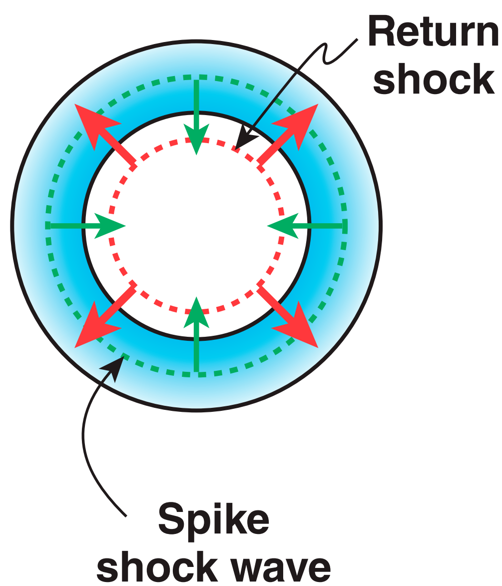
Shock ignition* is a two-step process that has the potential to provide large fusion gains





The ignitor shock wave significantly increases its strength as it propagates through the converging shell.

TC8918f

*R. Betti *et al.*, Phys. Rev. Lett. 98, 155001 (2007).

The laser-energy coupling is uncertain at high spike intensities

FSC

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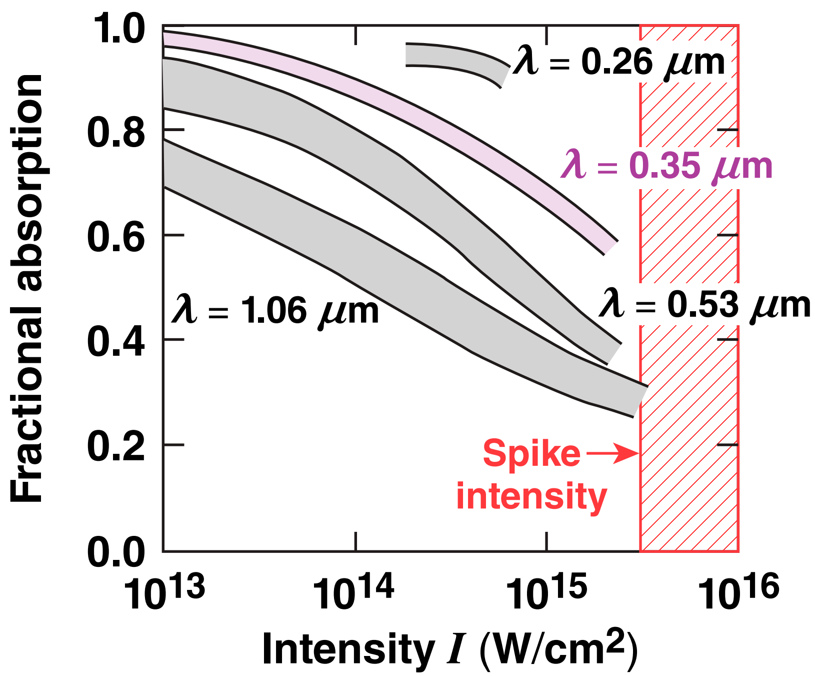


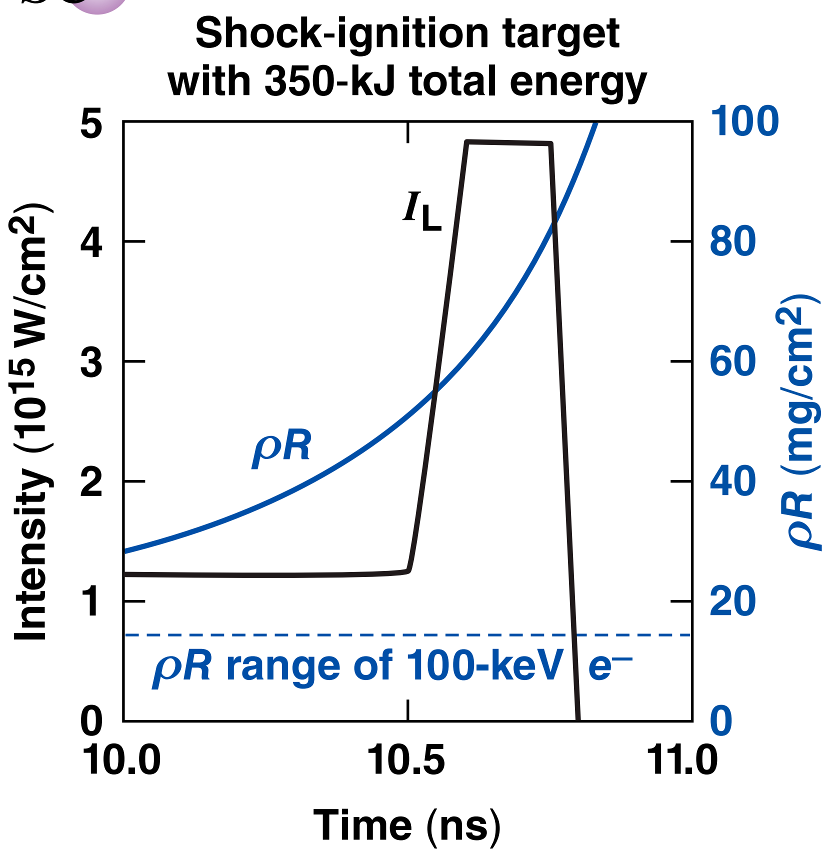
- Inverse bremsstrahlung absorption decreases with laser intensity*
- Kinetic effects become important for high intensities
- Experiments must test the scaling of ablation pressure with spike intensity

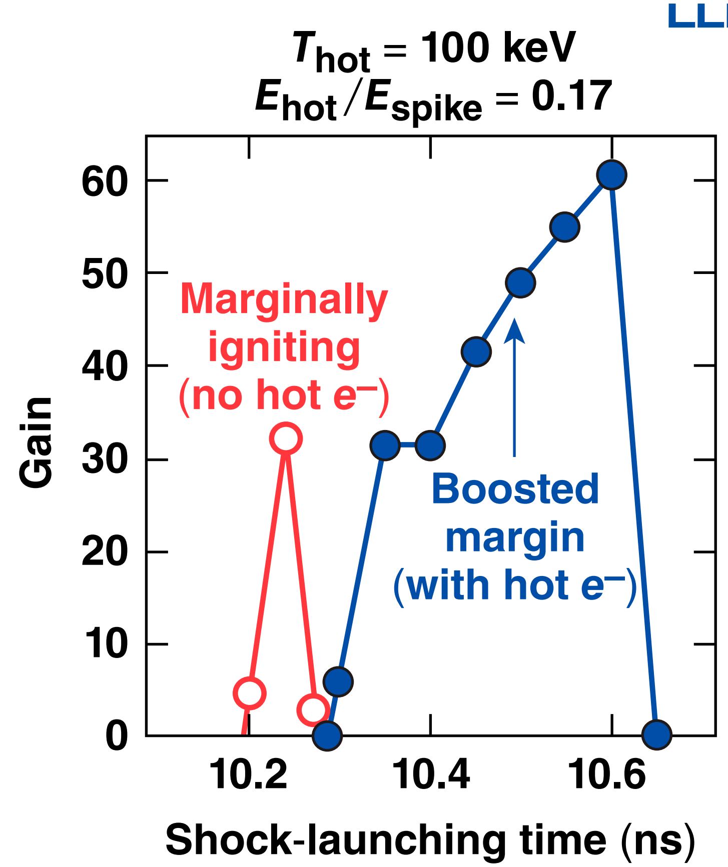
- Critical issues for shock ignition
  - demonstrate a minimum ~300-Mbar spike-generated ablation pressure
  - demonstrate hot-electron temperatures of ≤150 keV generated by the spike

*F. Amiranoff *et al.*, in *Plasma Physics Controlled Nuclear Fusion Research 1986* (IAEA, Vienna, 1987), Vol. 3, pp. 79–92.

E23579

Laser–plasma interaction during the spike pulse and hot-electron generation are important issues for shock ignition

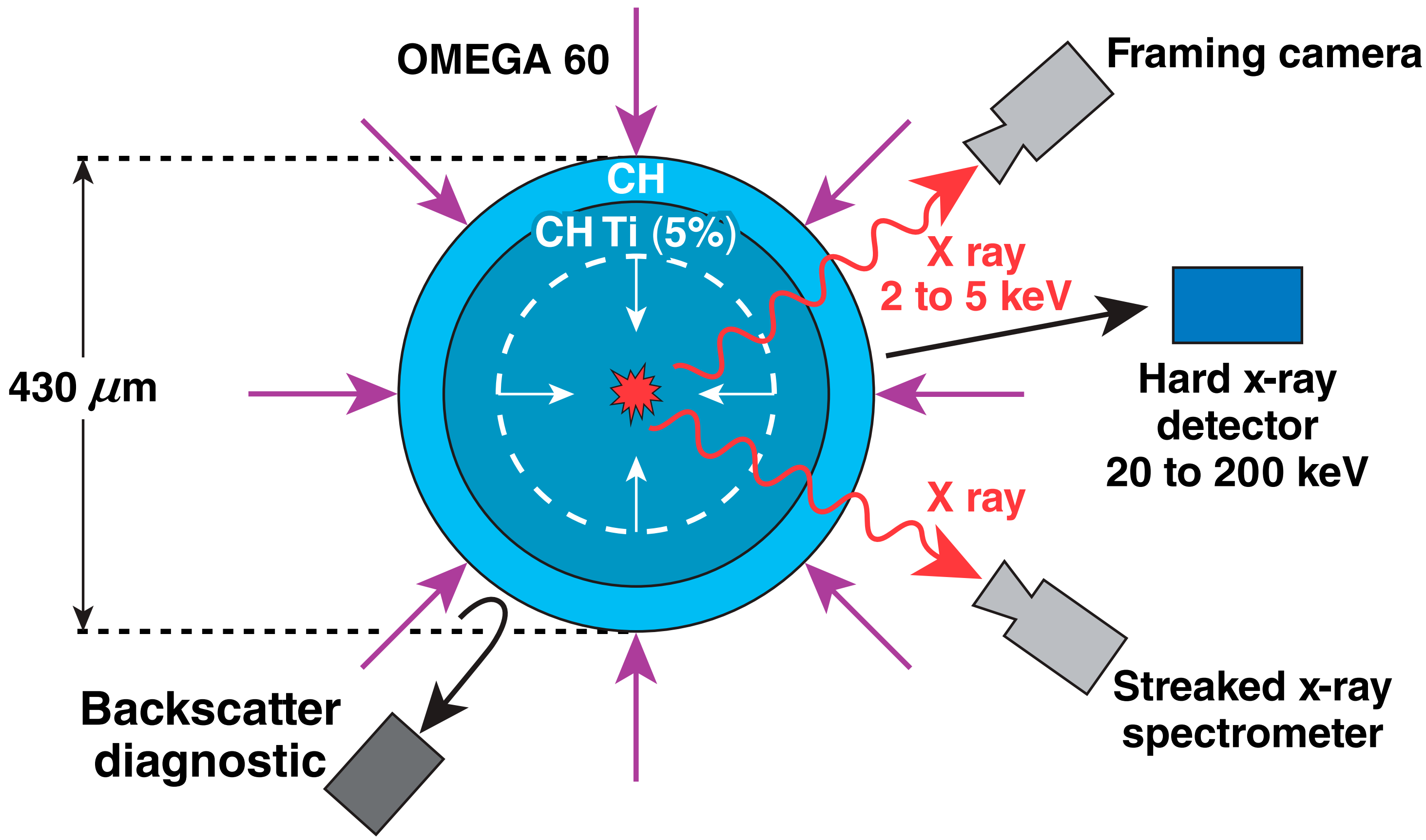




If the ρR is high enough, hot electrons are stopped in the outer regions of the shell.

R. Betti *et al*., J. Phys., Conf. Ser. 112, 022024 (2008);
S. Gus'kov *et al*., Phys. Rev. Lett. 109, 255004 (2012);
and A. R. Piriz *et al*., Phys. Plasmas 19, 122705 (2012).

An OMEGA platform has been developed to study the generation of strong shocks and hot-electron production in solid spherical targets



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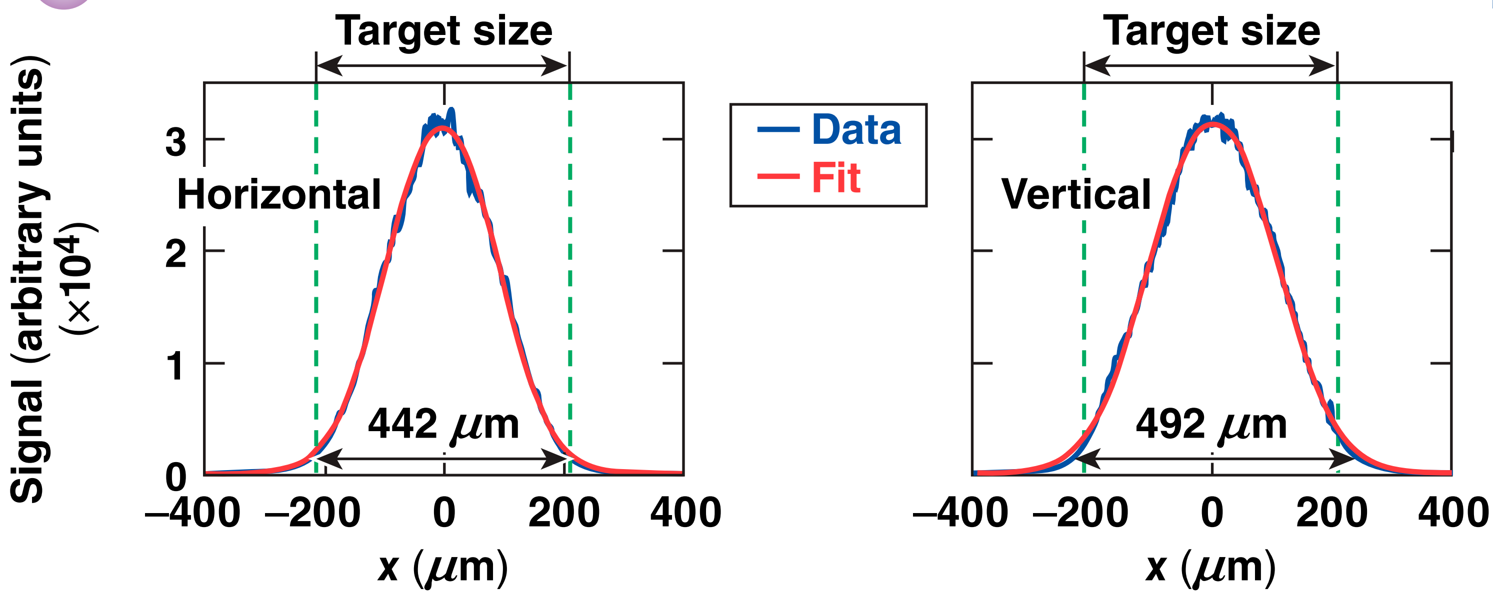
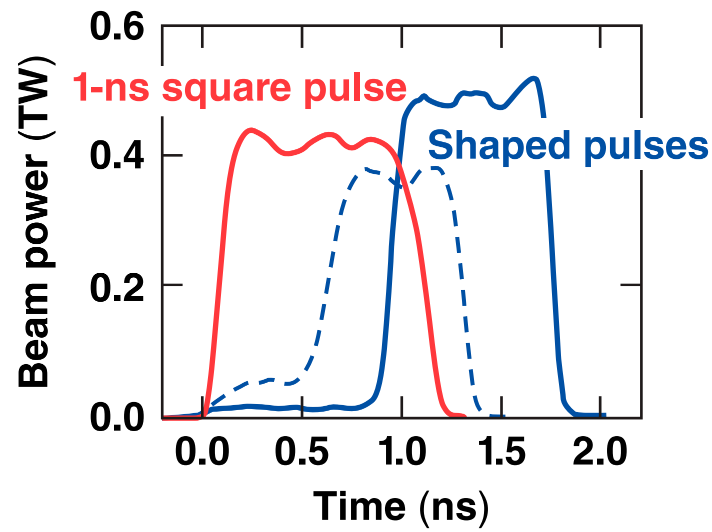
The laser focus in all 60 high-intensity beams matches the size of the small solid target

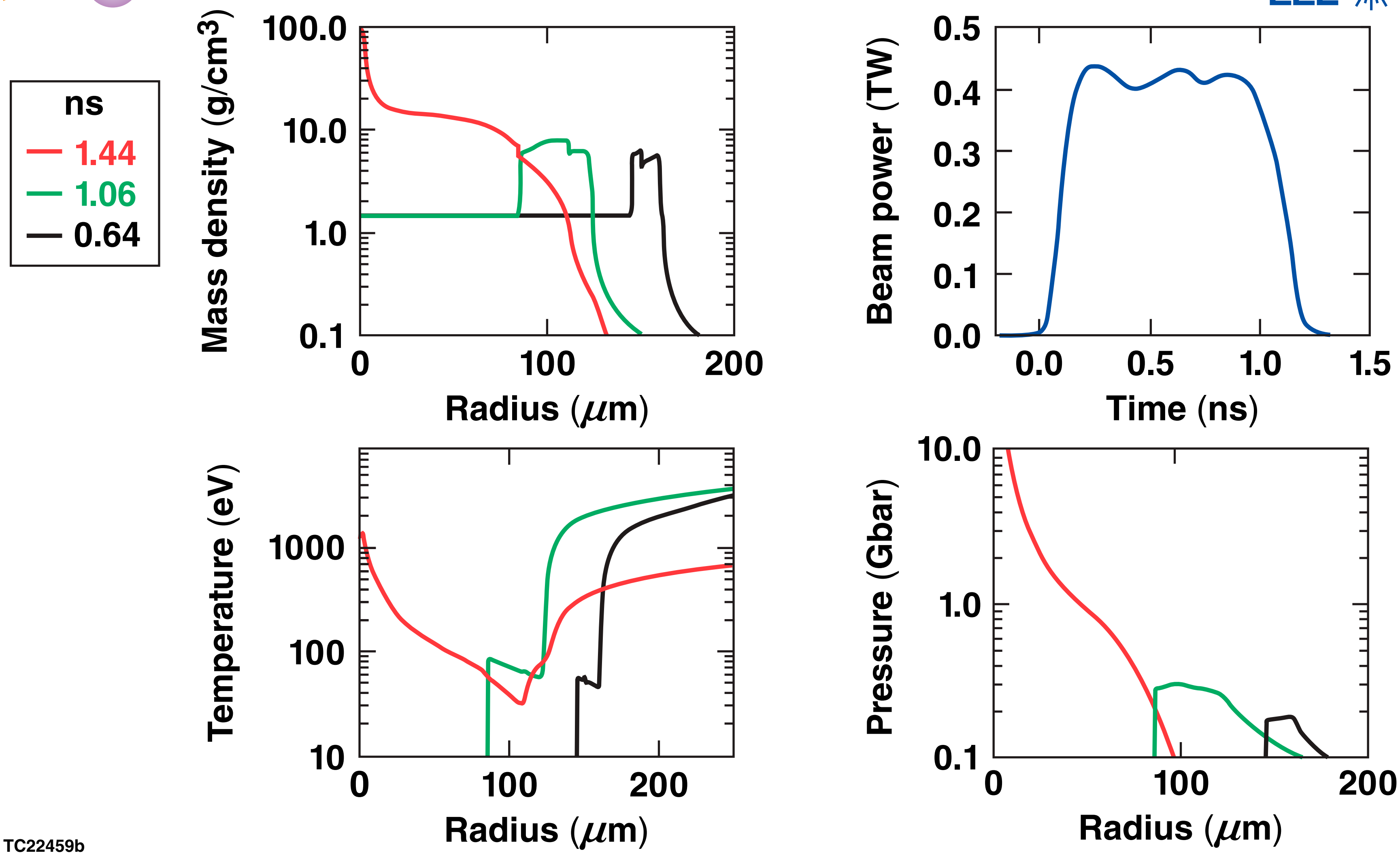


- Phase plates
- Distributed polarization rotators
- Smoothing by spectral dispersion
- $I \sim 5 \times 10^{15}$ W/cm^2
- Density scale length $L_{n_c/4}$ ~120 μm



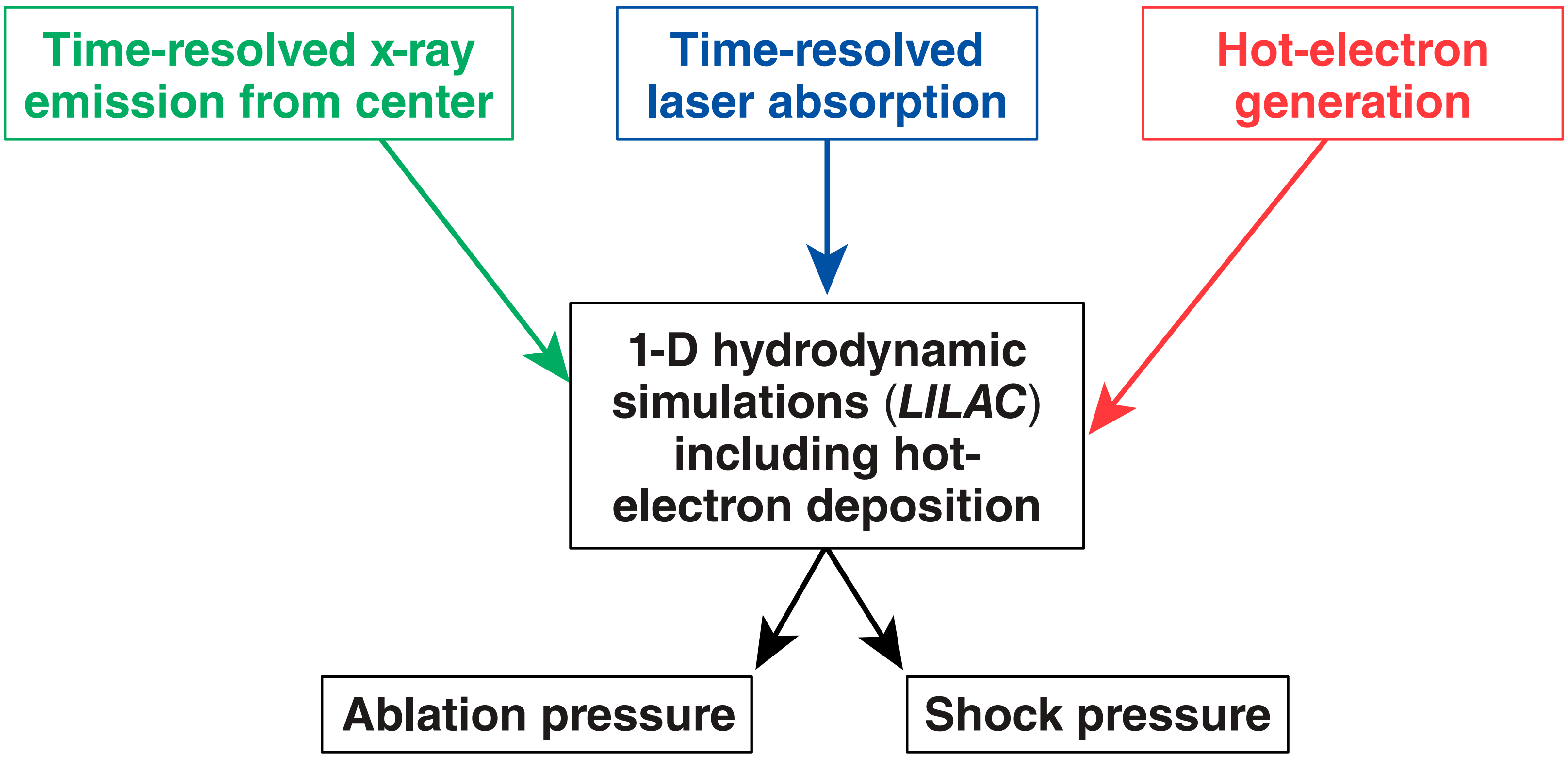
TC22458b

One-dimensional *LILAC* simulations predict a strong spherical shock wave that converges in the center of the solid target

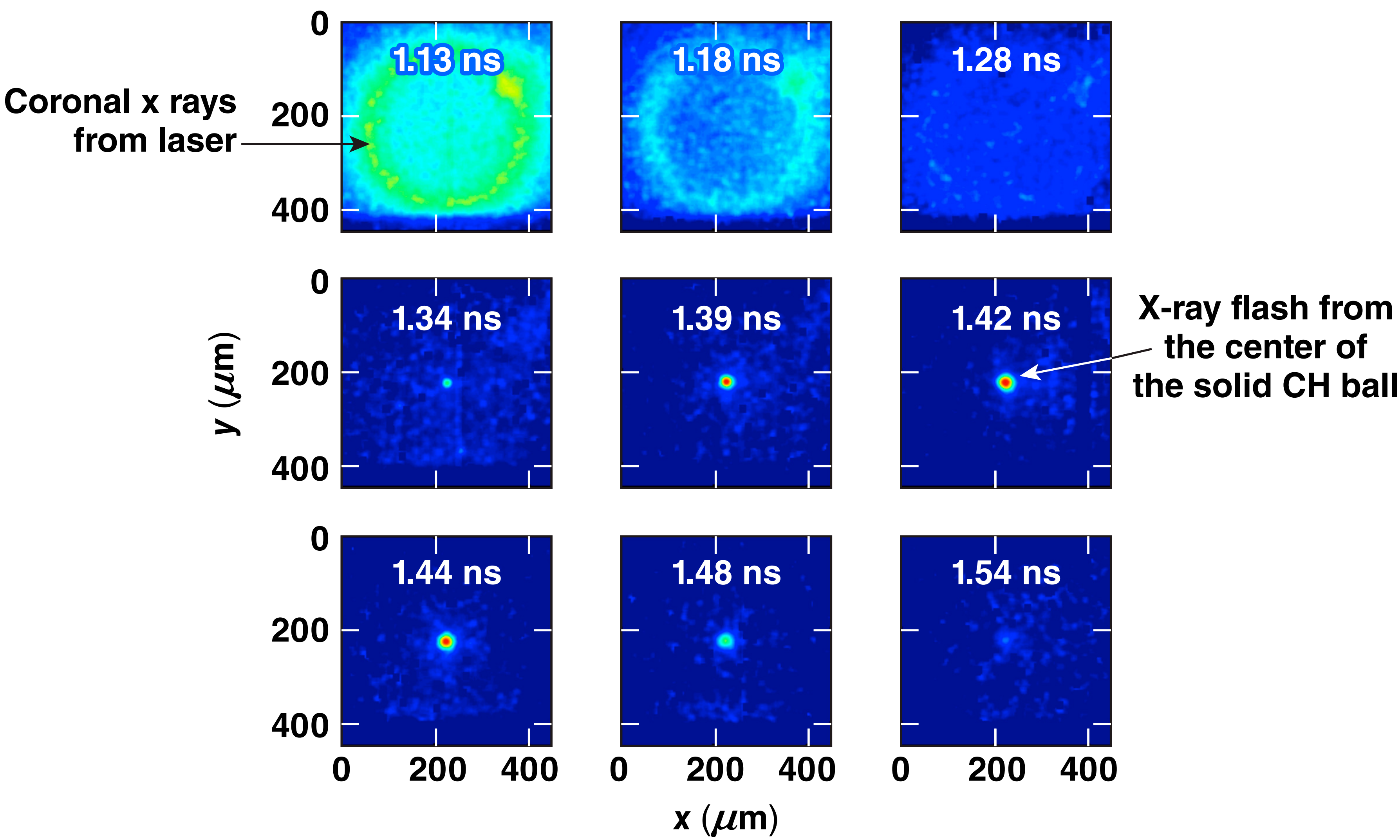


TC22459b

The ablation and shock pressures are inferred from simulations that are constrained by experimental observables



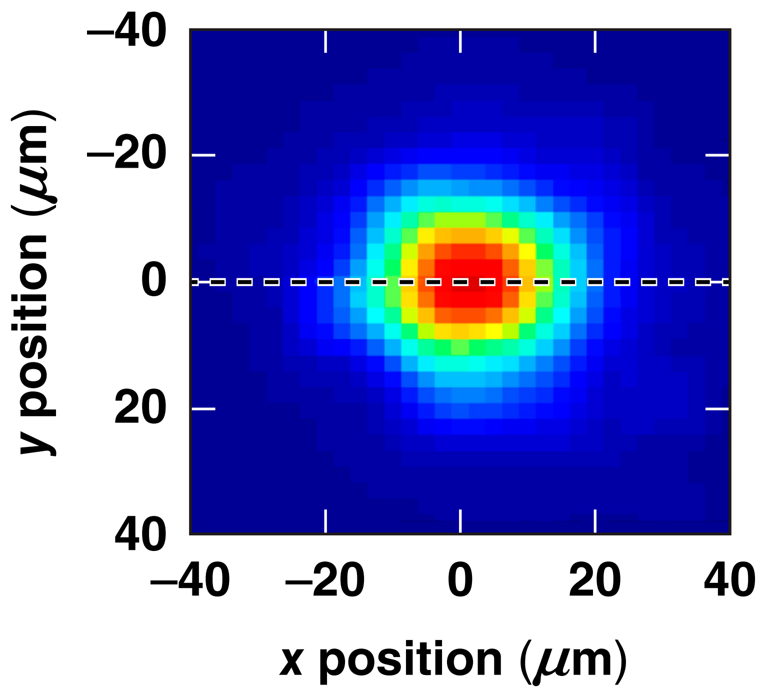
An x-ray framing camera captured a short x-ray flash at the time when the shock converged in the center

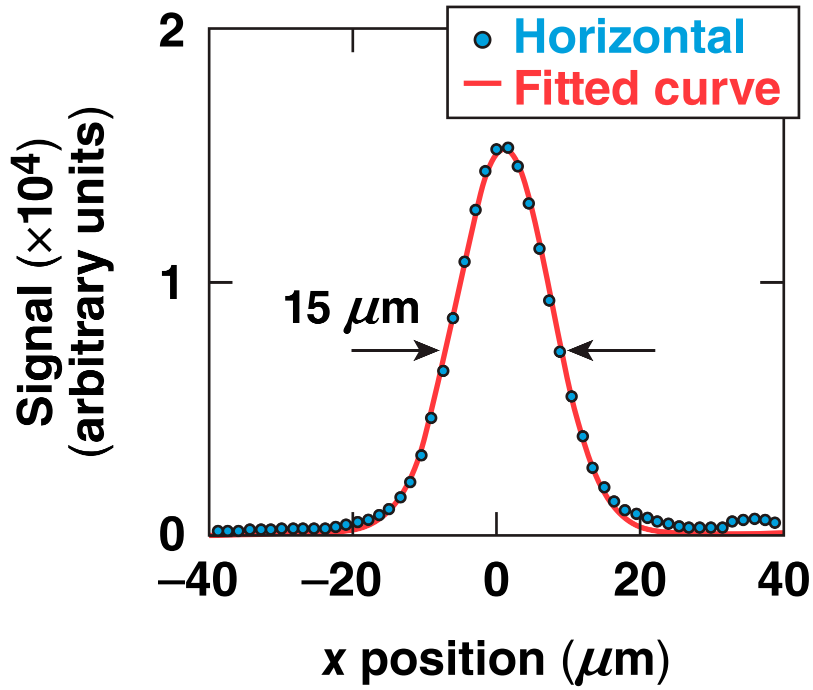


E23233a

The x-ray flash was emitted from a small volume of ~10^3 μm^3

Framing-camera images
from target center

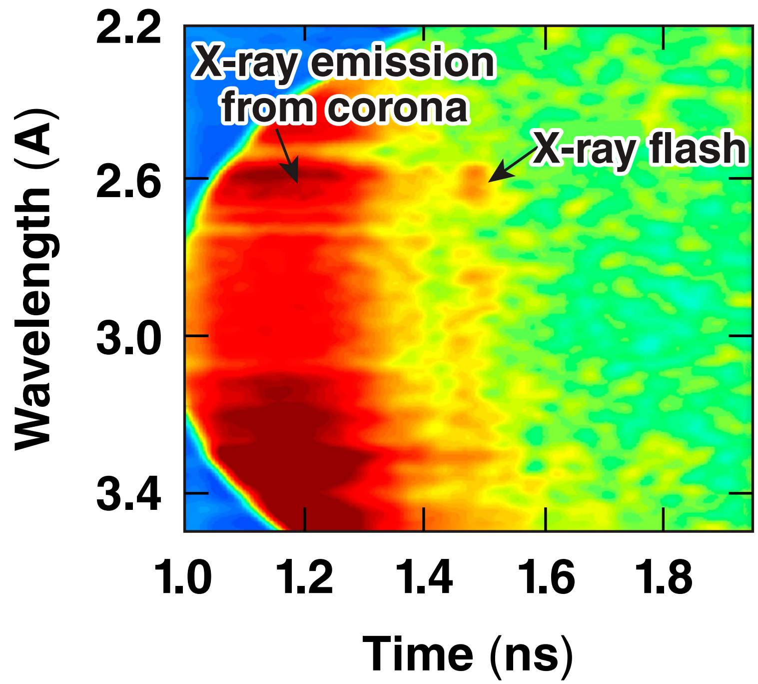


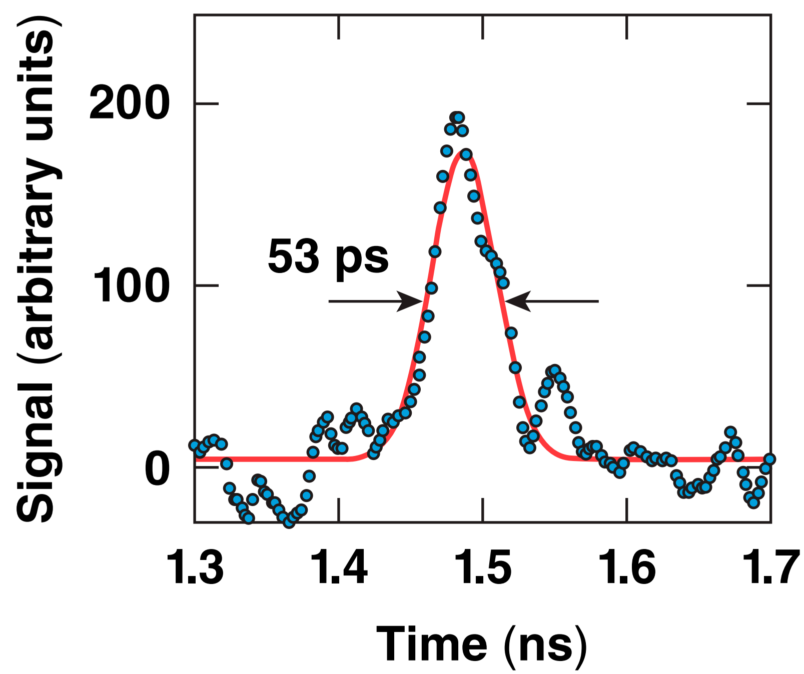


Deconvolved spatial
emission: ~9μm

E22462c

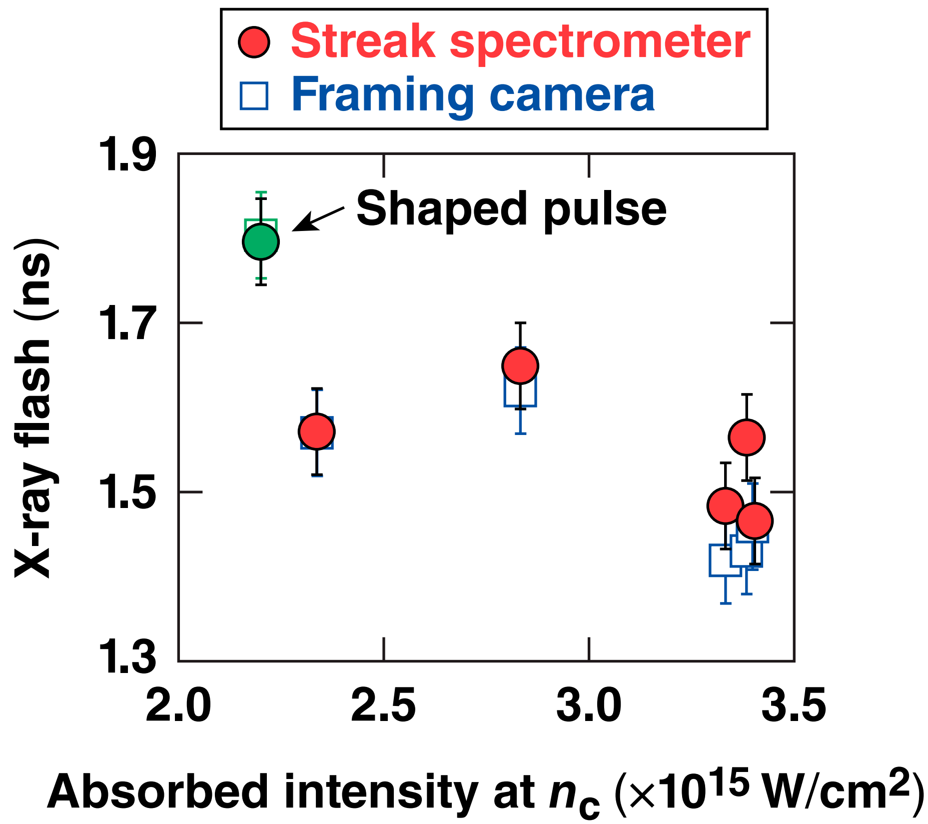
The x-ray flash was measured with a streaked x-ray spectrometer





Deconvolved emission time: ~35 ps

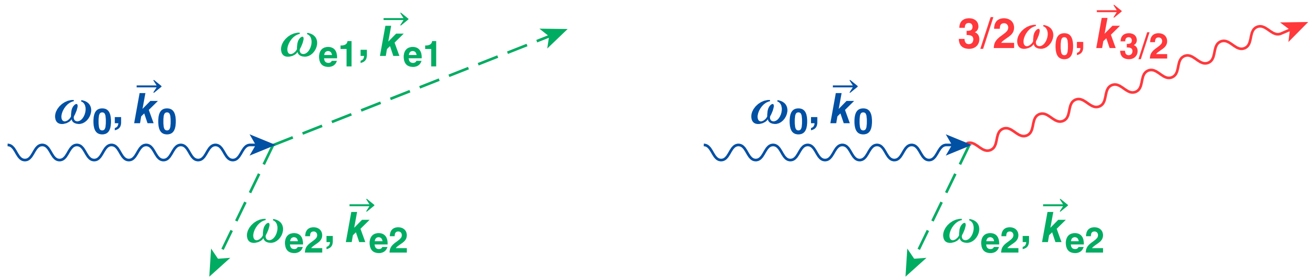
There is a good agreement in the x-ray framing camera and streaked spectrometer measurements

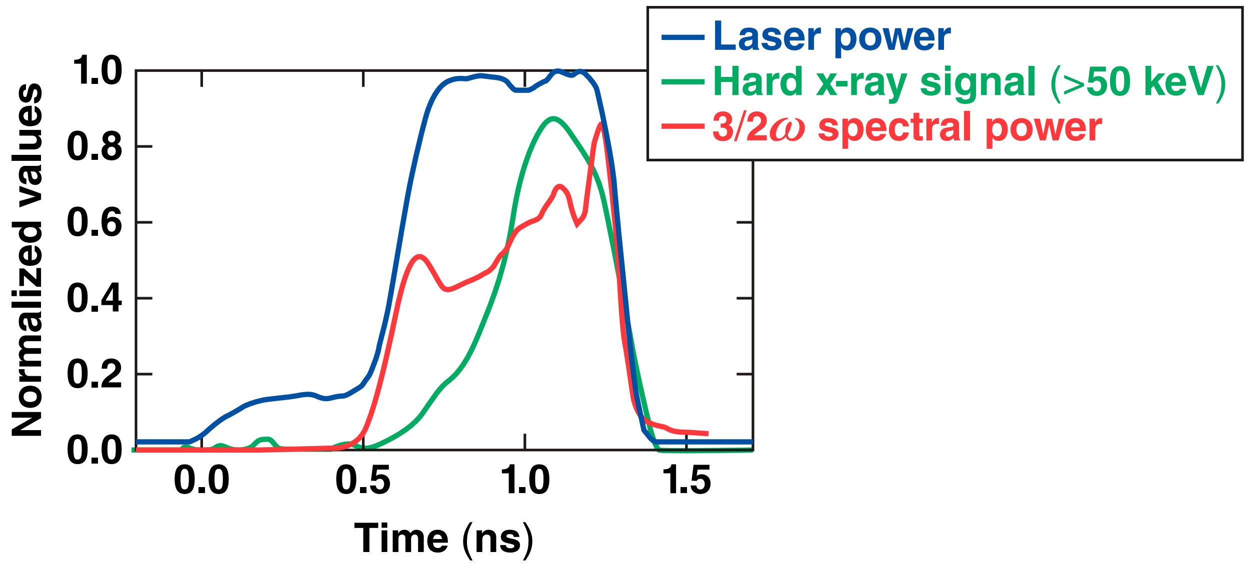


The two-plasmon decay (TPD) instability and stimulated Raman scattering (SRS) are the dominant hot-electron–generation mechanisms

$n_e \sim n_c/4$

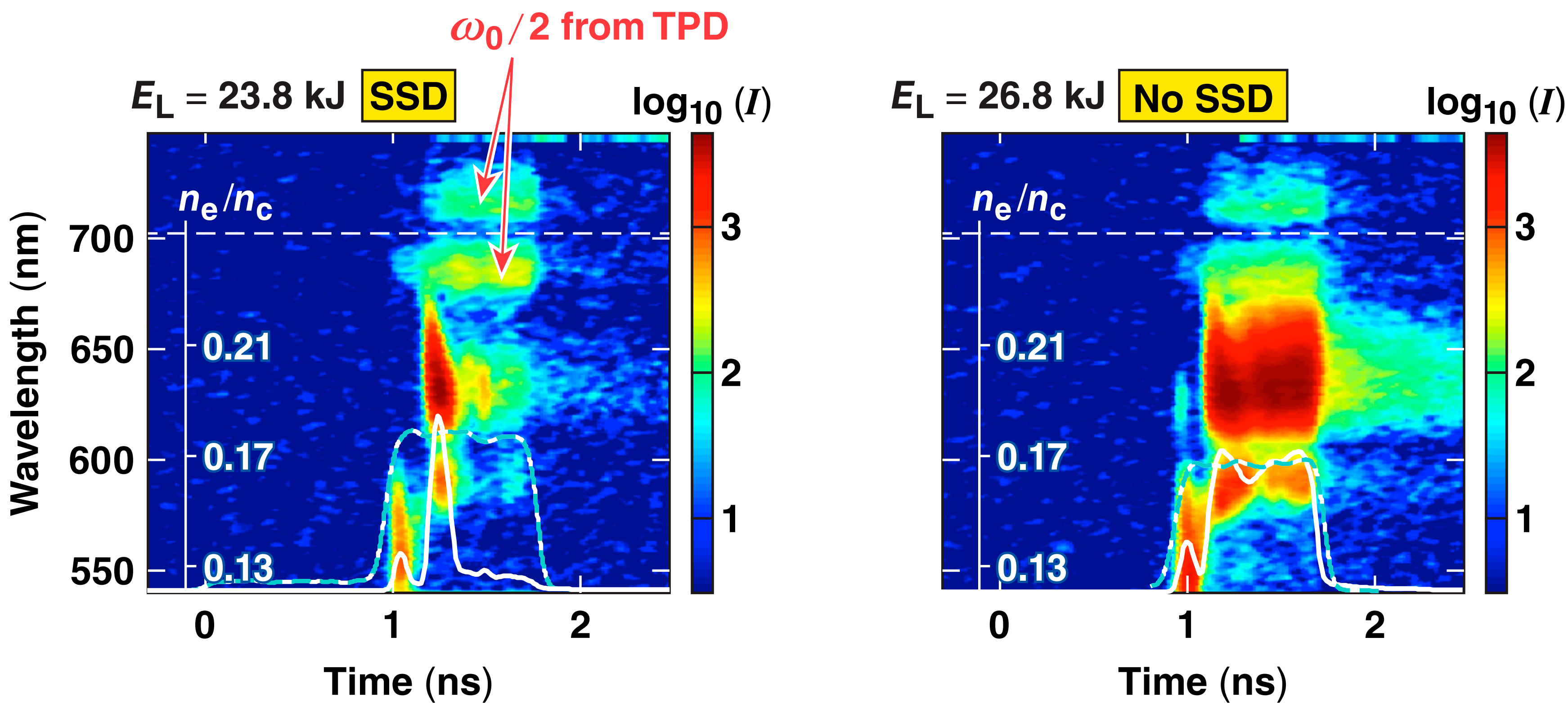
$\omega_{e1} \sim \omega_{e2} \sim \omega_0/2$





E23189a

SRS increases significantly [~5× in the full-aperture backscatter station (FABS)] when smoothing by spectral dispersion (SSD) is turned off*



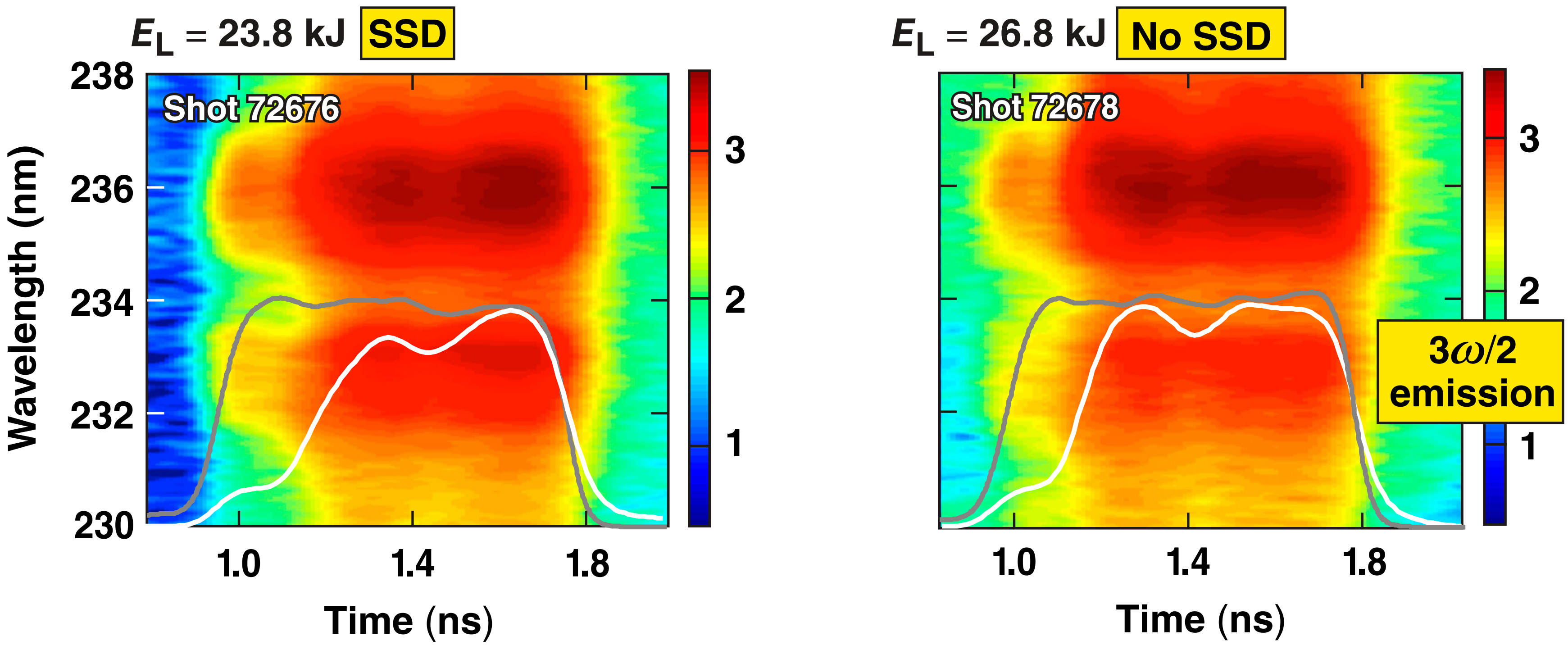
E_{SRS} (arbitrary units) = 291

E_{SRS} (arbitrary units) = 1563

*W. Seka *et al.*, PO4.00011, this conference.

E23226a

TPD is largely unaffected by SSD*



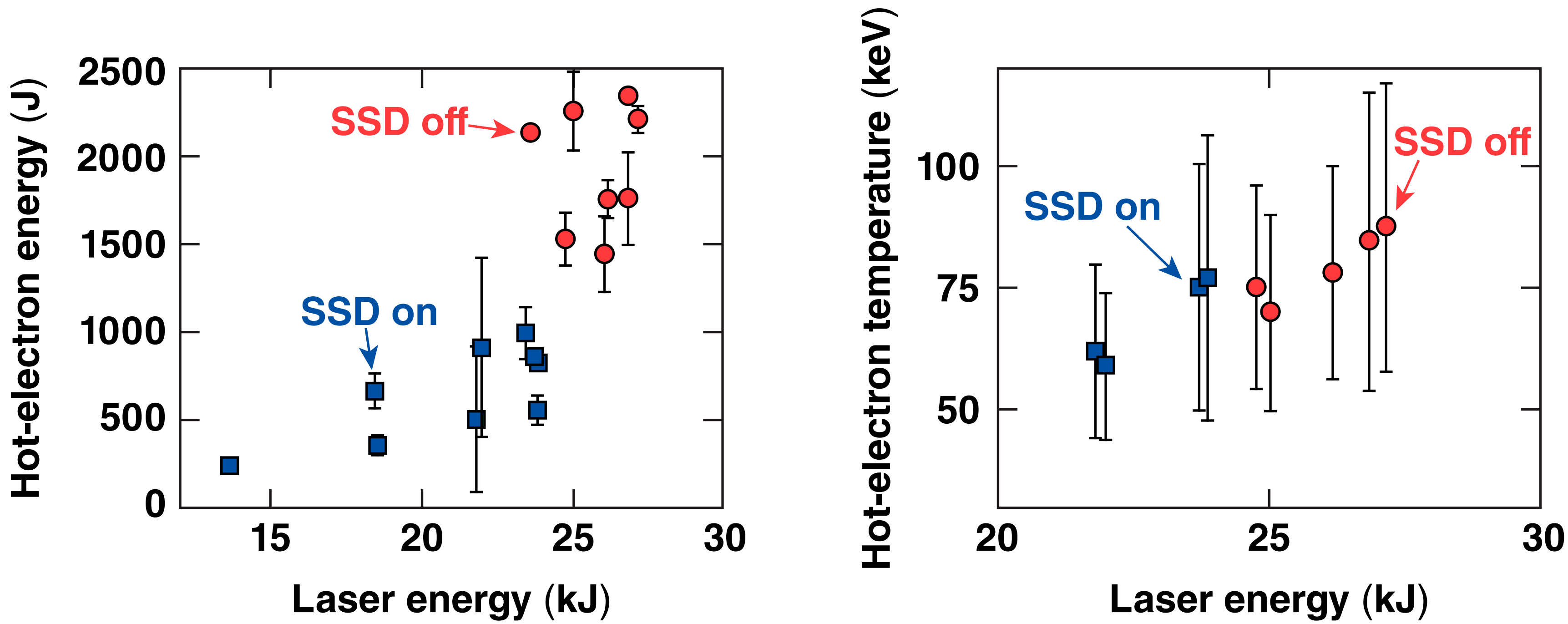
E_{TPD} (arbitrary units) = 420

E_{TPD} (arbitrary units) = 328

E23227a

*W. Seka *et al*., Phys. Plasmas 16, 052701 (2009).

Up to 9% of the laser energy is converted into hot electrons

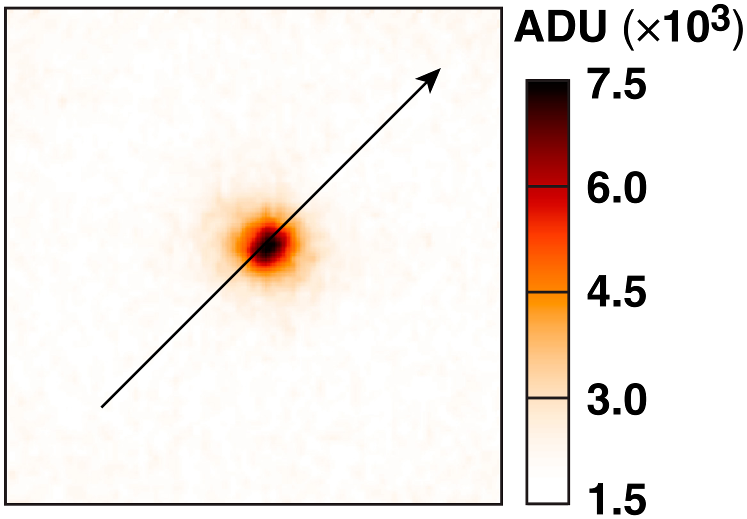


The instantaneous conversion efficiency reaches up to ~15%.

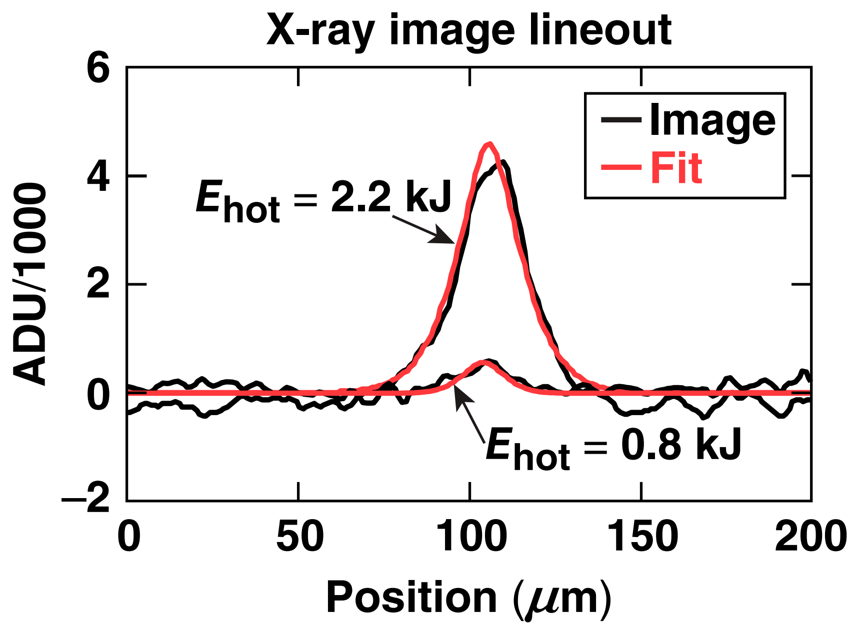
TC11478a

The increase in hot-electron production correlates with an increase in the x-ray emission from the shock flash from the target center

Time-integrated x-ray microscope* data from the core center



200 × 200-μm region



Instrument spatial resolution ~7 μm

Stronger x-ray signal indicates stronger shocks.

E23191a

*F. J. Marshall *et al.*, Phys. Plasmas 5, 1118 (1998).

The x-ray flash is later when SSD is turned on compared to when SSD is off

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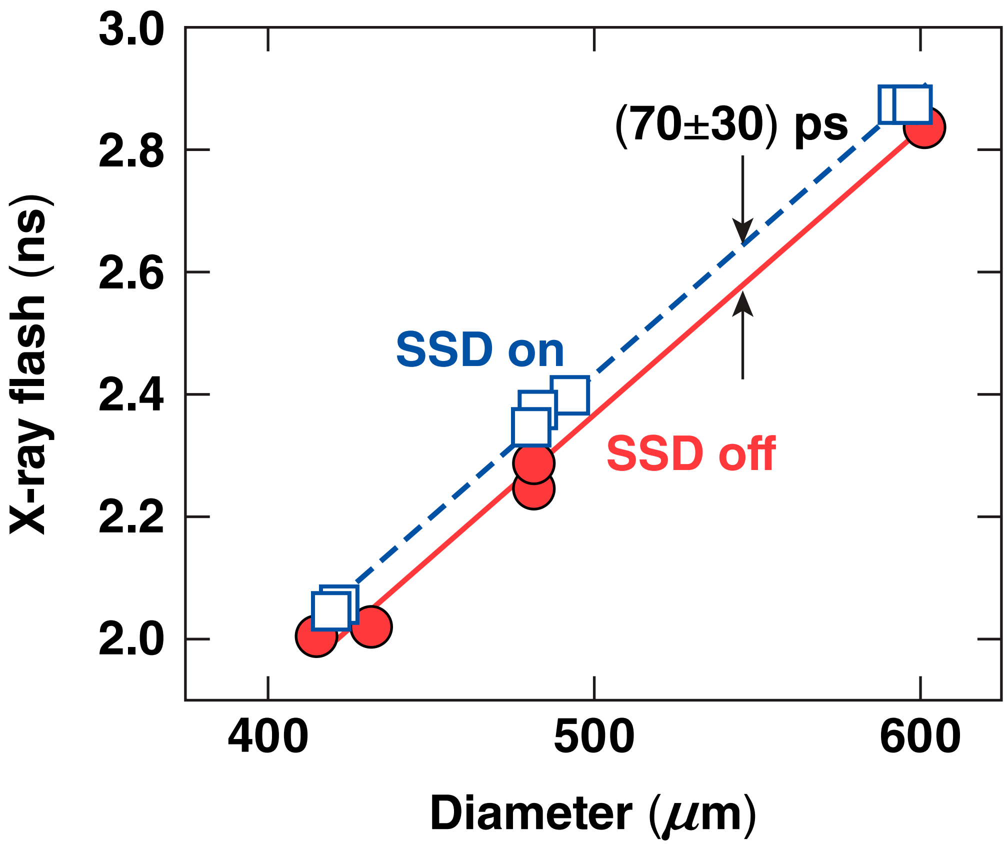
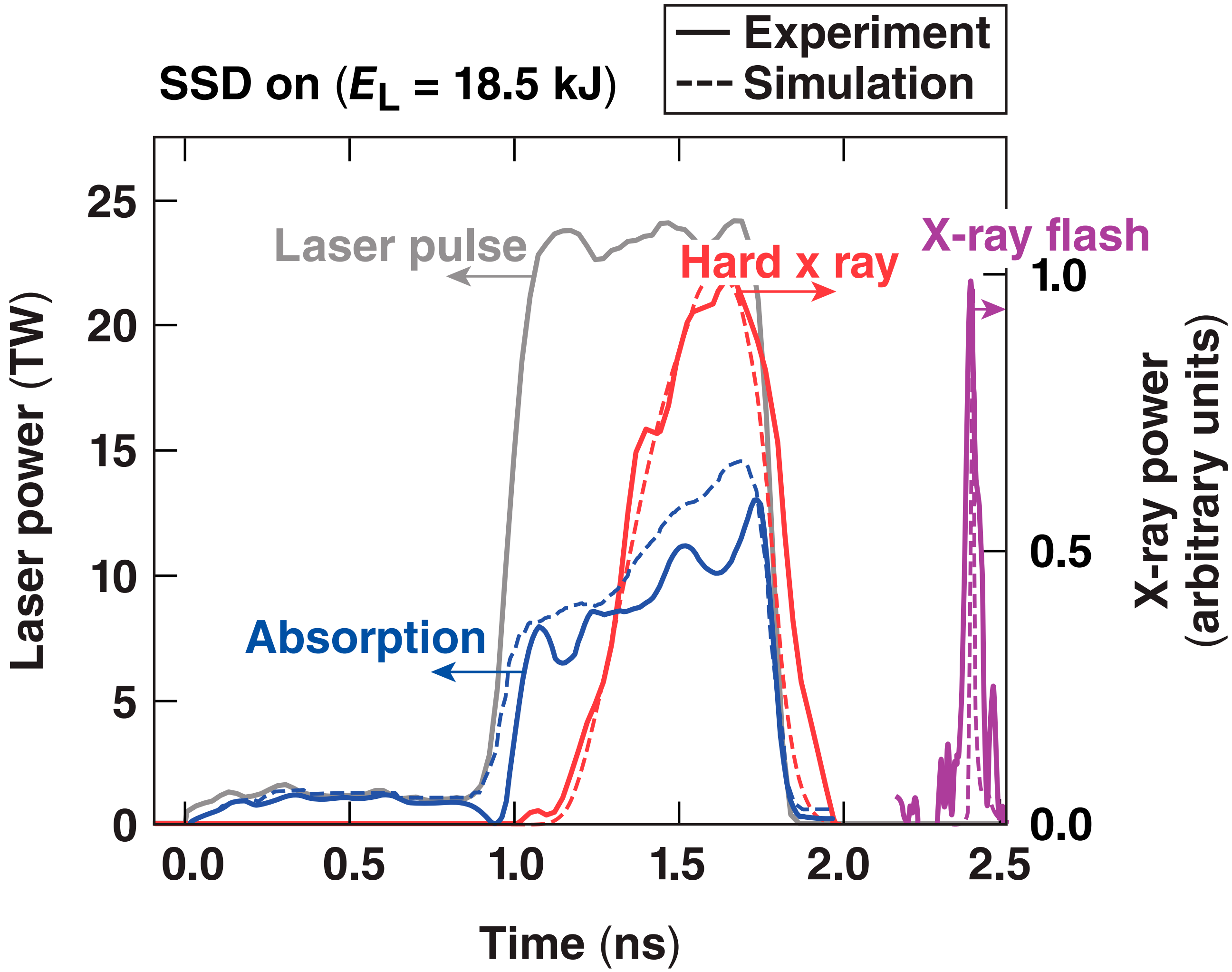


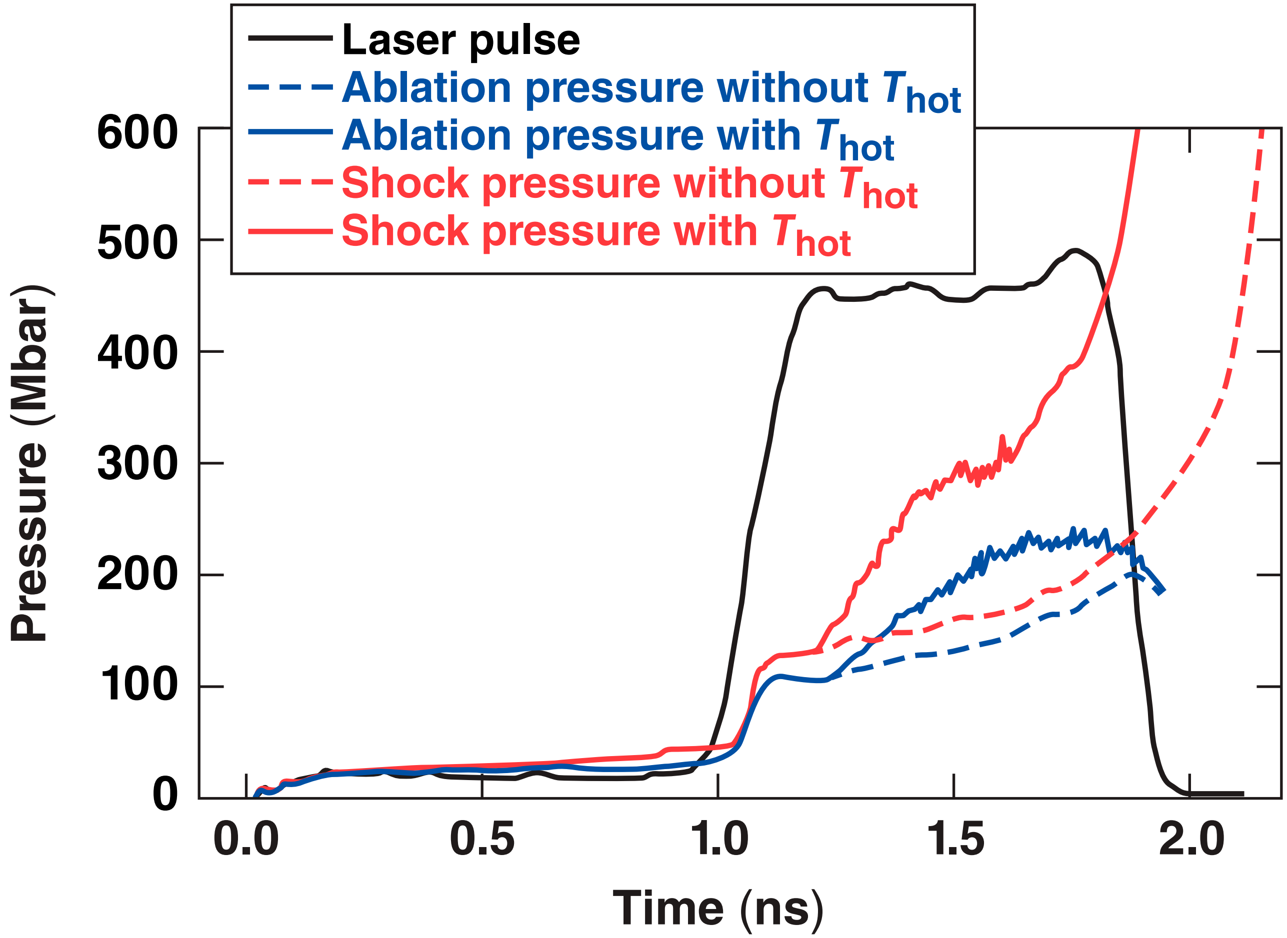
An earlier flash time for when SSD is off indicates a stronger shock.

Hydrodynamic *LILAC* simulations* are constrained by the hard x-ray emission, laser absorption, and shock x-ray flash



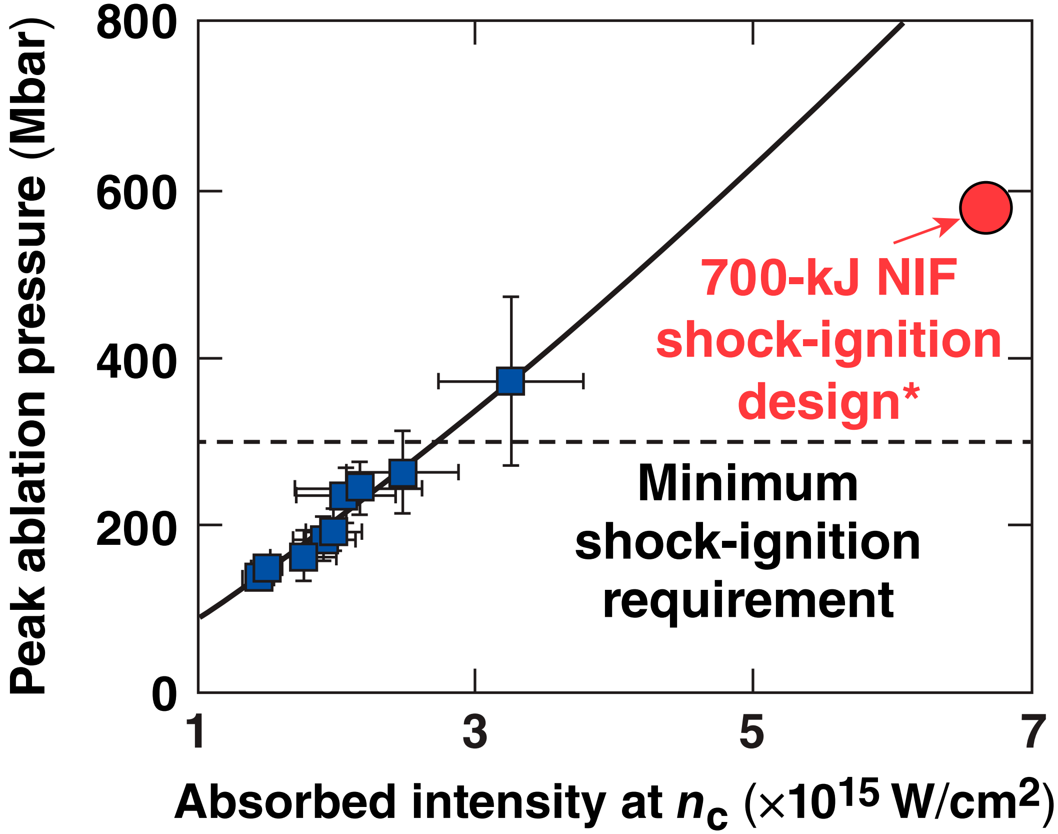
*R. Nora *et al.*, GO6.00005, this conference.

The highly constrained *LILAC* simulations are used to infer the ablation and shock pressures



E23271a

The simulated maximum ablation pressures exceed the minimum required pressure of 300 Mbar for shock ignition

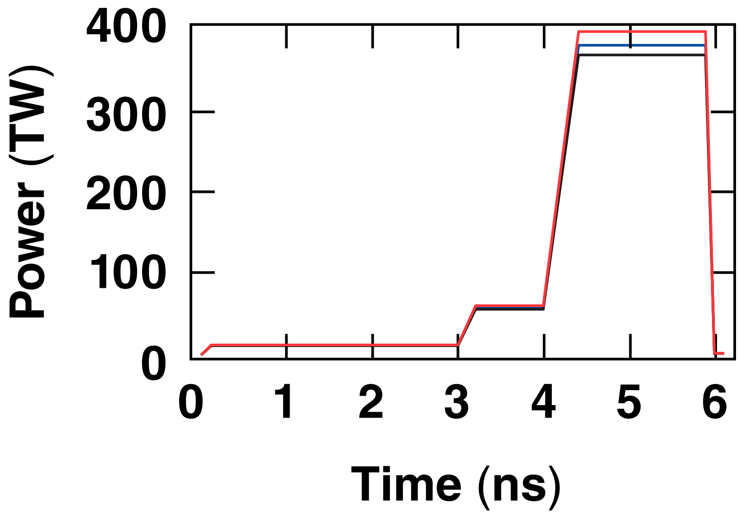


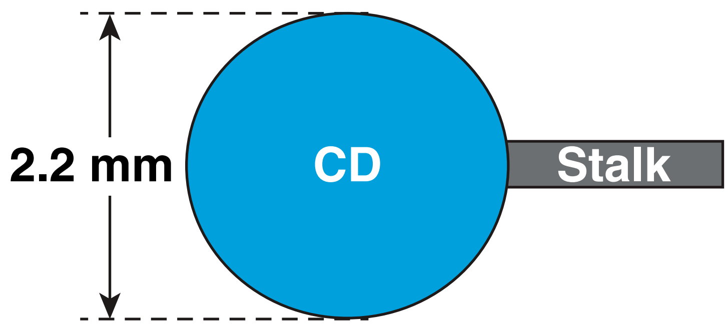
- The simulations match all the experimental observables

E23581

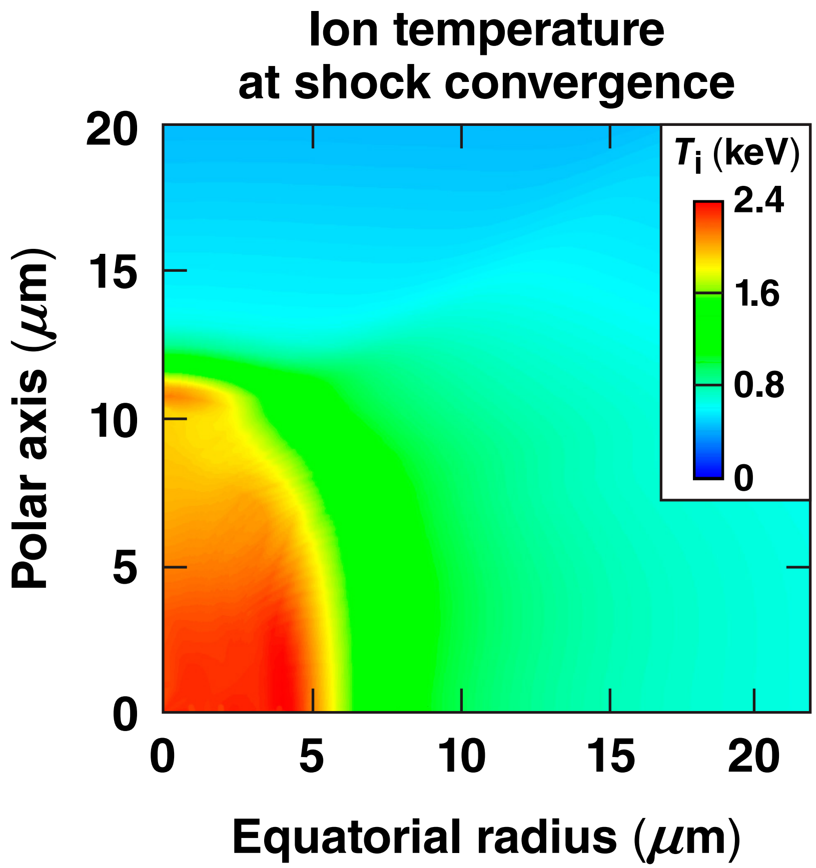
*K. S. Anderson *et al.*, Phys. Plasmas 20, 056312 (2013).

Strong-shock experiments are proposed* on the NIF





Density scale length at $n_c/4$: ~350 μm



*R. Nora *et al.*, "Ultra Strong Spherical Shocks for Studies of Material Properties at Multi-Gigabar Pressures," proposal submitted to the NIF, LLNL, Livermore, CA (September 2014).

E23653

Summary/Conclusions

The inferred ablation pressures from spherical strong-shock experiments exceed the 300 Mbar required for shock ignition

- Pressures are inferred from simulations of experiments studying the shock propagation in solid spheres
- Laser–plasma instabilities produce large amounts of hot electrons (T_{hot} < 100 keV), reaching up to ~9% of the laser energy at absorbed intensities of 3×10^{15} W/cm^2
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