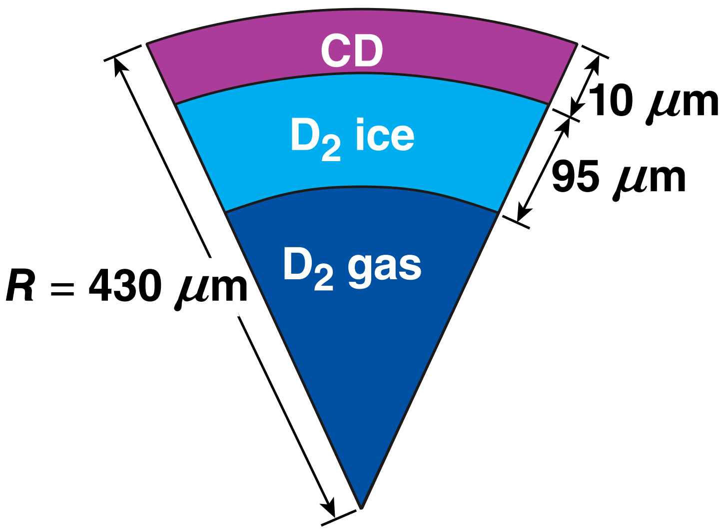
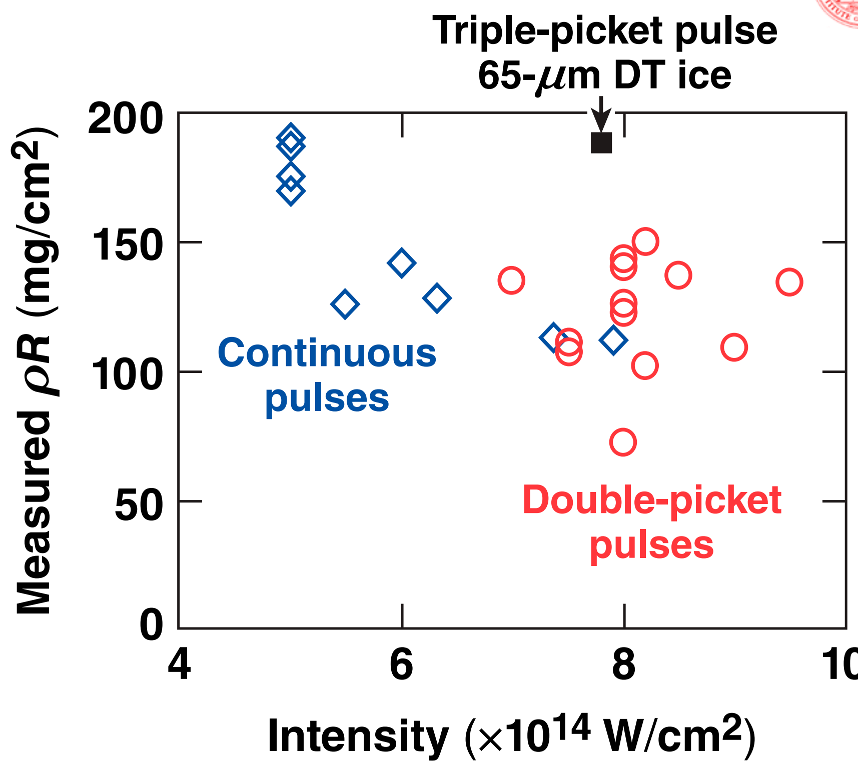
Cryogenic Target Performance on OMEGA





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Summary

The understanding of cryogenic target implosions is essential to achieving ignition on the NIF

- Recent OMEGA experiments have demonstrated ignition-relevant areal densities at intensities of ~5×10^{14} W/cm^2.
- Higher implosion velocities require an intensity of ~1×10^{15} W/cm^2, previously shown areal density degredation.
- Three- and four-shock coalescence is being investigated for better adiabat control in cryogenic targets.
- High *Z* ablators significantly reduce hot-electron preheat.

Significant progress is being made in understanding high intensity cryogenic target implosions.

Collaborators

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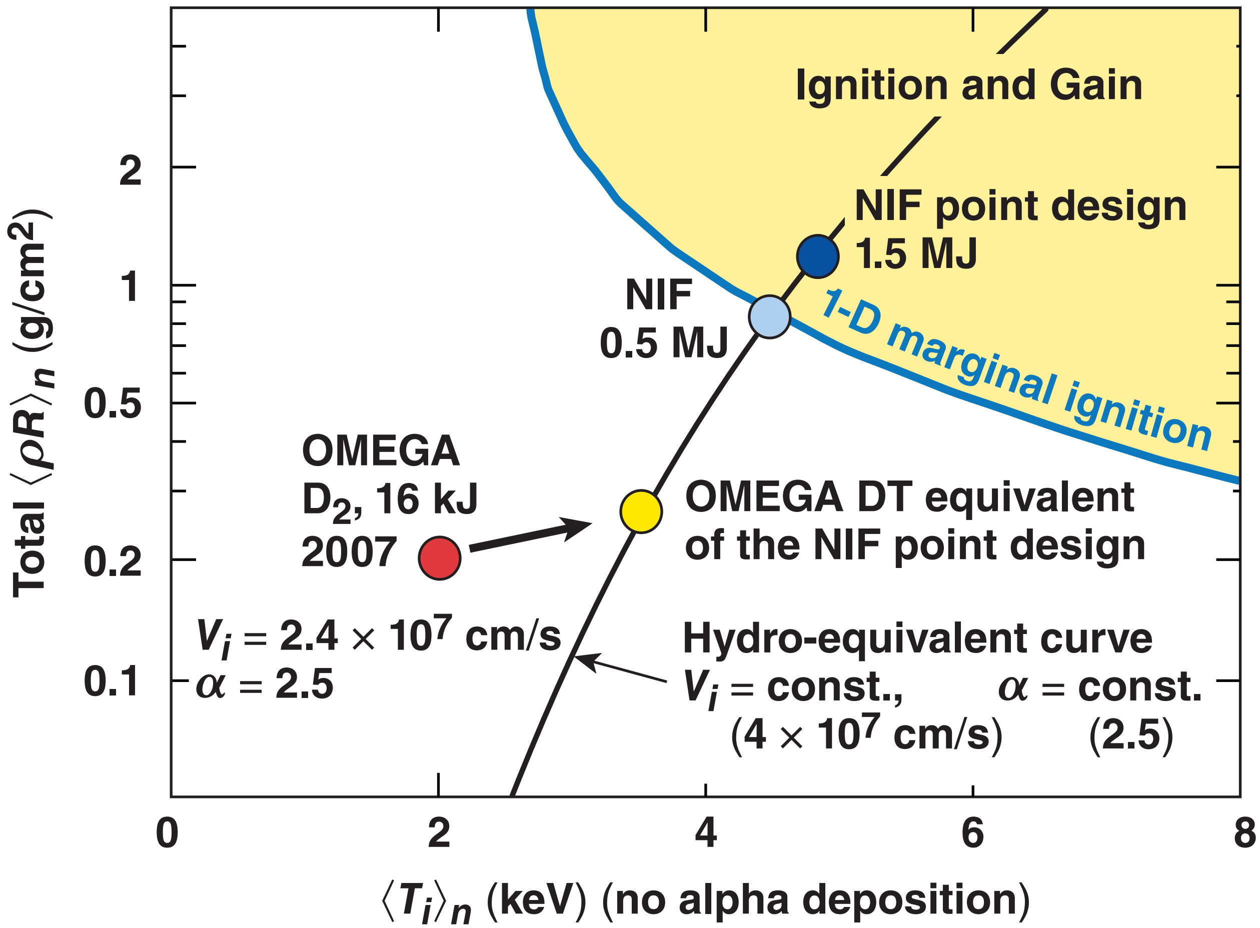
Path to T_i

Direct-drive research is on a path to ignition on the NIF

- Ignition-relevant areal densities have been achieved.
- The next step is to increase T_i.



I1772a

C. D. Zhou and R. Betti, Phys. Plasmas 15, 102707 (2008).

The fuel areal density and hot-spot ion temperature determine ignition performance

- Ignition relevant implosion velocities require drive intensities of ~10^{15} W/cm^2
- Previous results showed degradations at high intensities
- Areal density (ρR)
  - compressibility—planar foil shock compression
  - shock timing and strength—multiple pickets
  - preheat—high-*Z* ablators
  - hydrodynamic instabilities—stabilization at high intensity
- Ion temperature (T_i)
  - implosion velocity—all high-intensity experiments
  - hydrodynamic instabilities—stabilization at high intensities
  - absorption/drive coupling—nonlocal model

Multiple shock-target designs show promise for achieving ignition relevant performance.

I1776

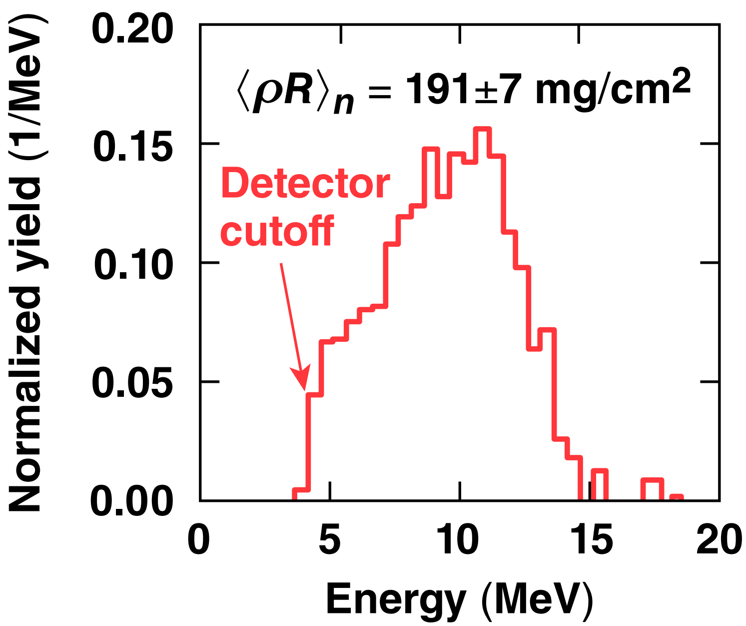
Areal Density

Ignition-relevant areal densities (up to ~200 mg/cm²) are achieved by accurate shock timing and mitigating fast-electron preheat

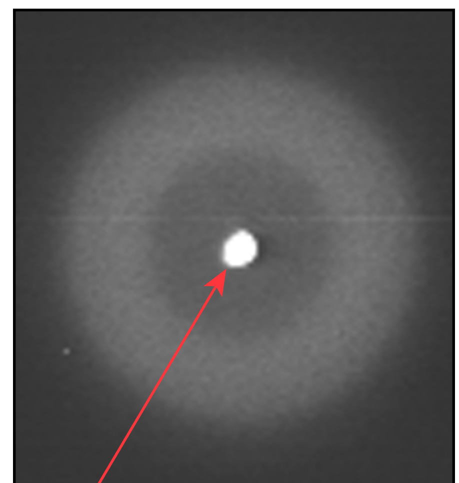
- Target design is tuned to be insensitive to the thermal-transport model and has a low hard x-ray signal.

10-μm CD cryogenic implosion

Secondary D^3He proton spectrum



X-ray pinhole camera



D_2 fuel density reaches ~100 g/cc (500× liquid density)

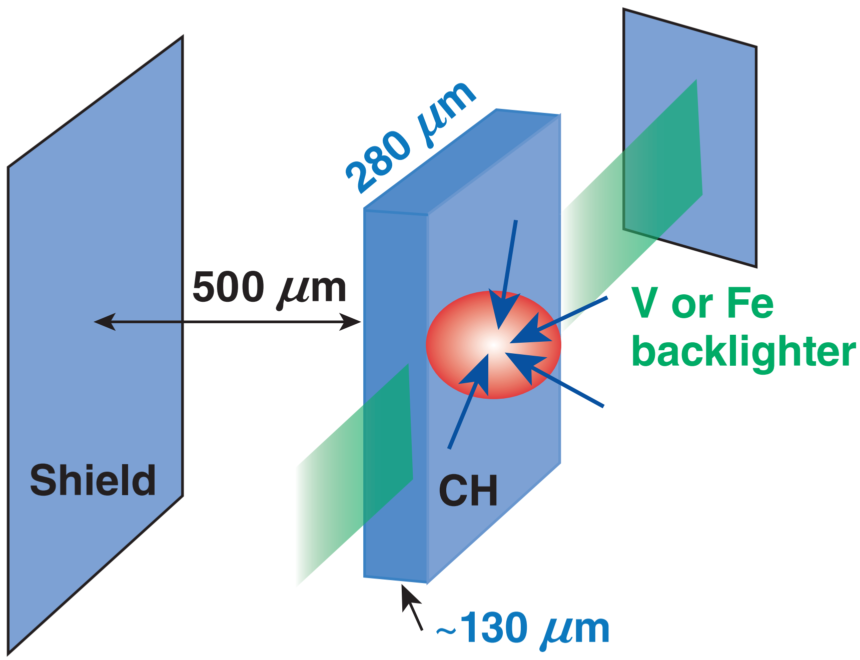
These are, by far, the highest areal densities measured in ignition-relevant laboratory implosions—very important for direct- and indirect-drive ignition.

I1742i

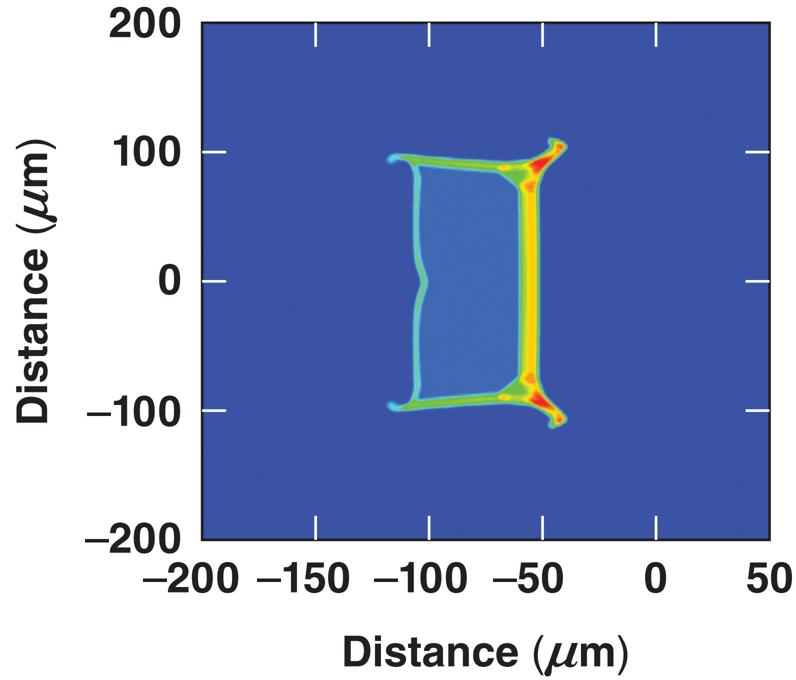
T. C. Sangster *et al*., Phys. Rev. Lett. 100, 185006 (2008).

Shock compression was measured with side-on radiography using planar, 130-μm-thick plastic targets

Experimental setup



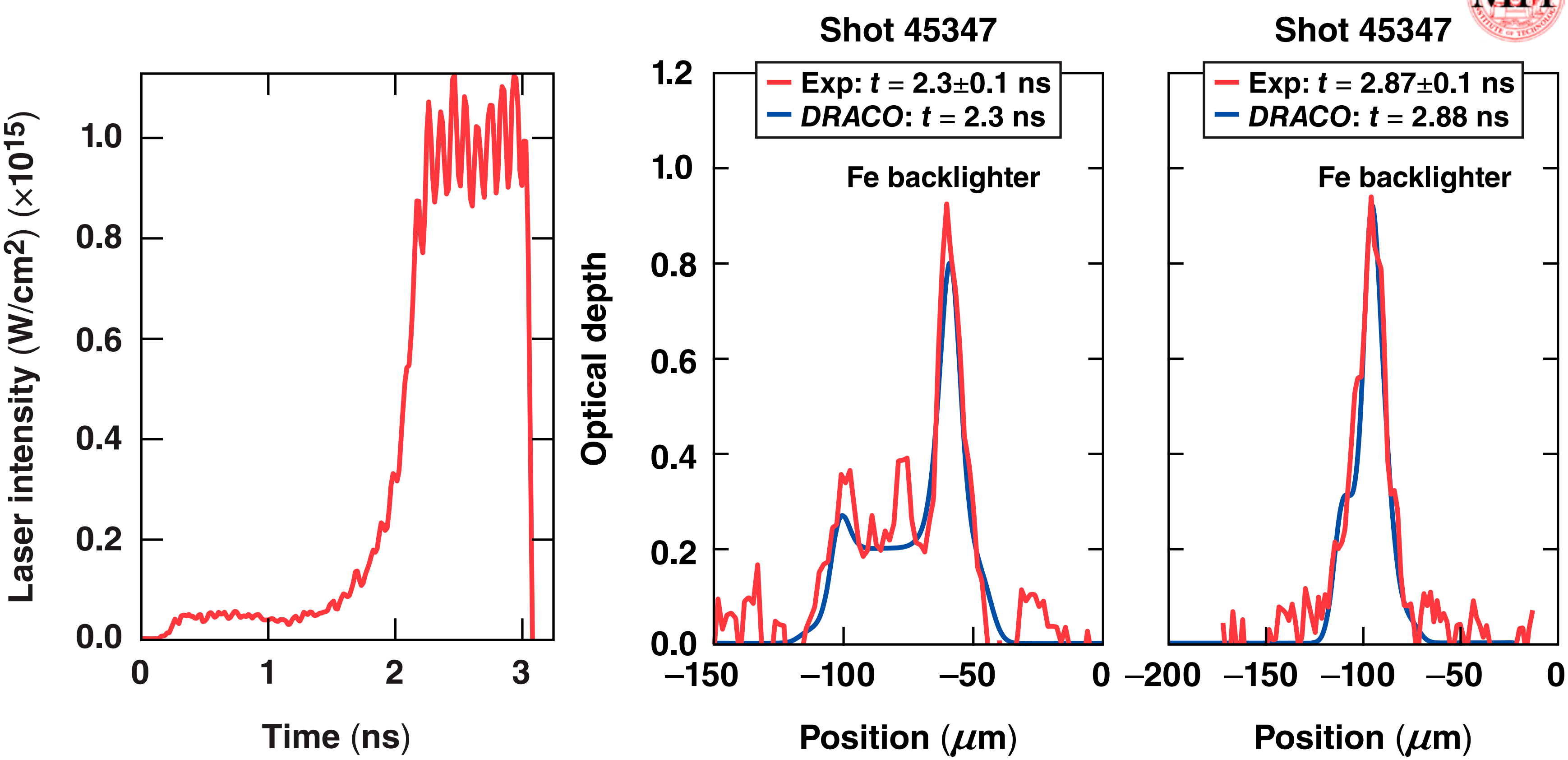
DRACO 2-D simulation



- Shock compression was measured with a framing camera using 1-ns square and 3-ns shaped pulses.
- Experimental spatial resolution was 10 μm, temporal resolution 40 ps.

TC7753d

DRACO simulations are in good agreement with experiments for shaped pulses

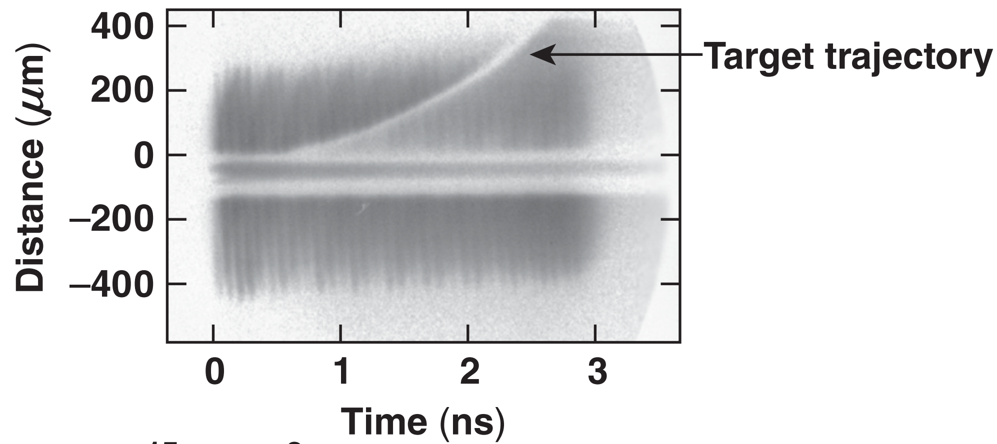


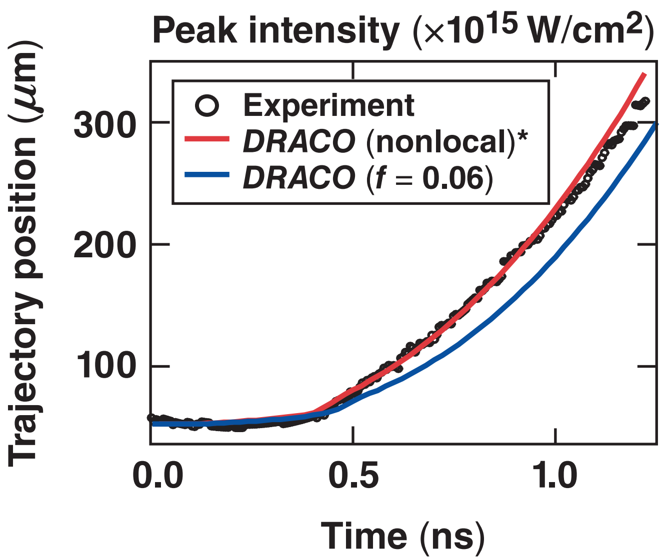
Peak compression of ~9× was achieved in planar targets.

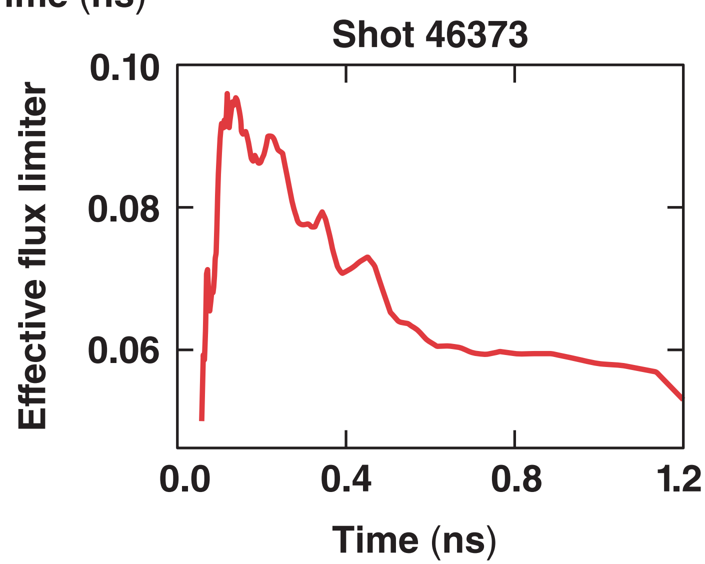
TC7755d

S. X. Hu *et al.*, Phys. Rev. Lett. 101, 055002 (2008).

The nonlocal model* resulting in effective time-dependent flux limiters better simulates the laser-target coupling at high intensities



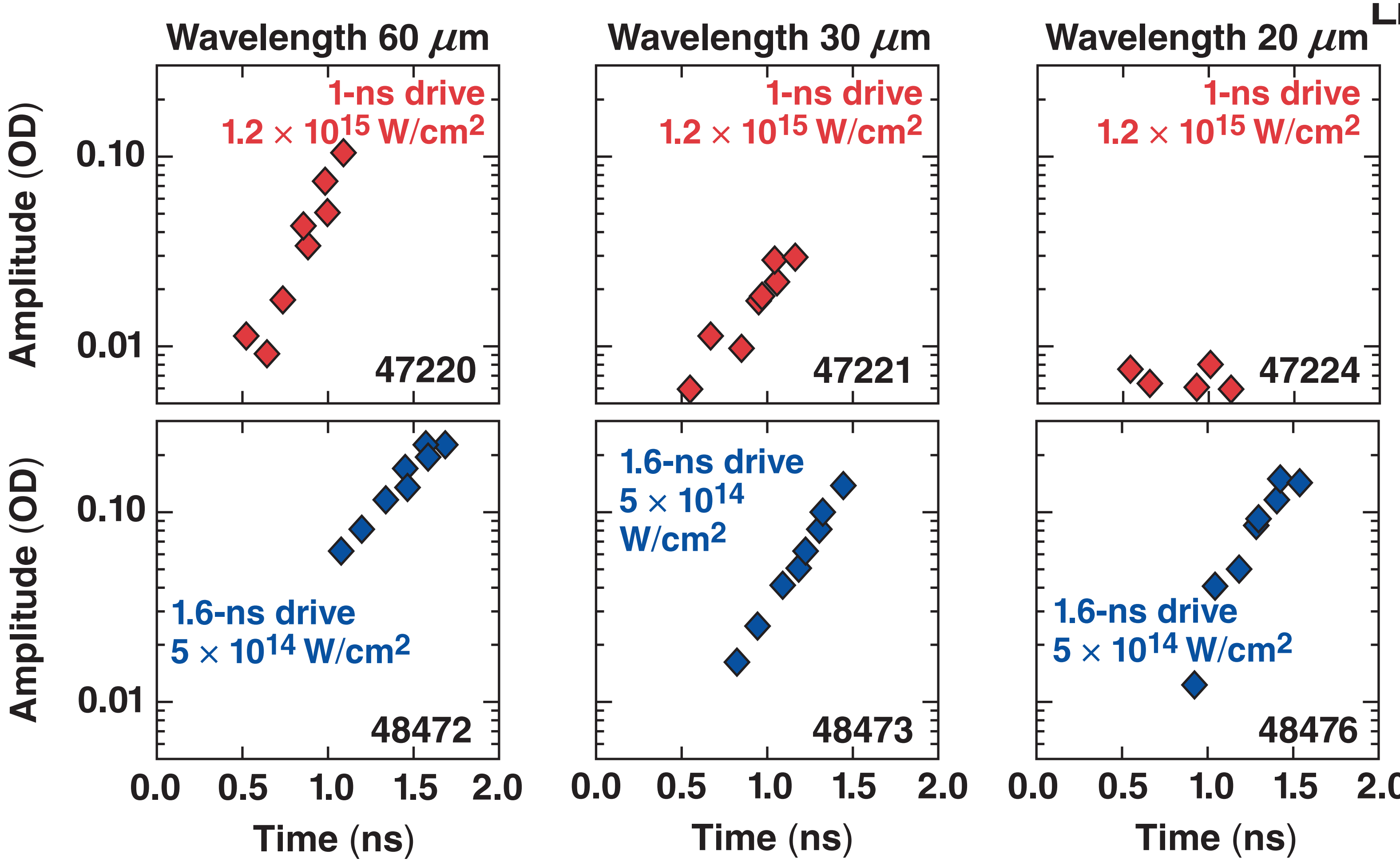




TC7976a

*V. N. Goncharov *et al.*, Phys Plasmas 13, 012702 (2006).
S. X. Hu *et al.*, Phys. Rev. Lett. 101, 055002 (2008).

The Rayleigh–Taylor growth is strongly stabilized at an intensity of 10^{15} W/cm^2 compared to 5×10^{14} W/cm^2



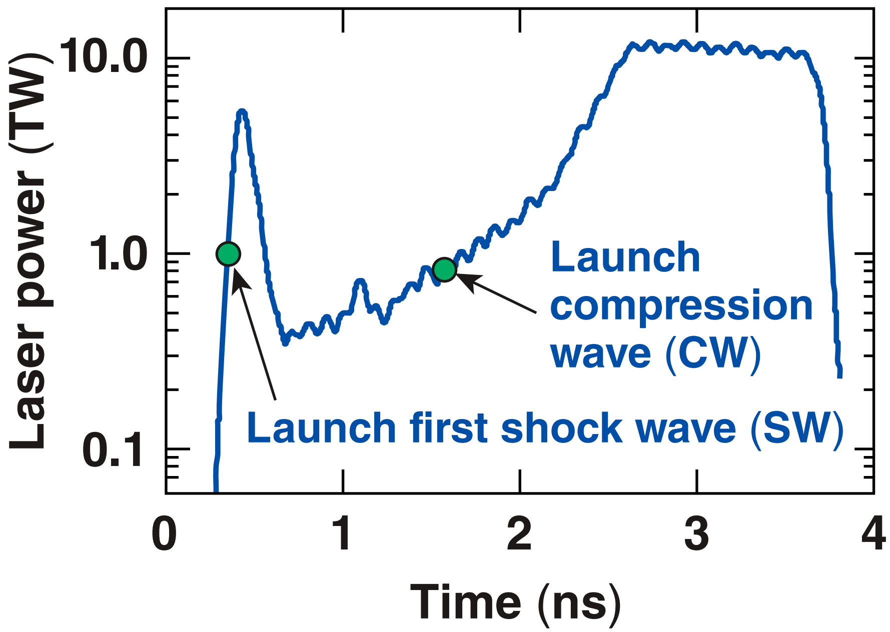
$$\text{RT growth rate } \gamma = 0.94\sqrt{\frac{kg}{1+kL_n}} - 1.5\,kV_a$$

U656c

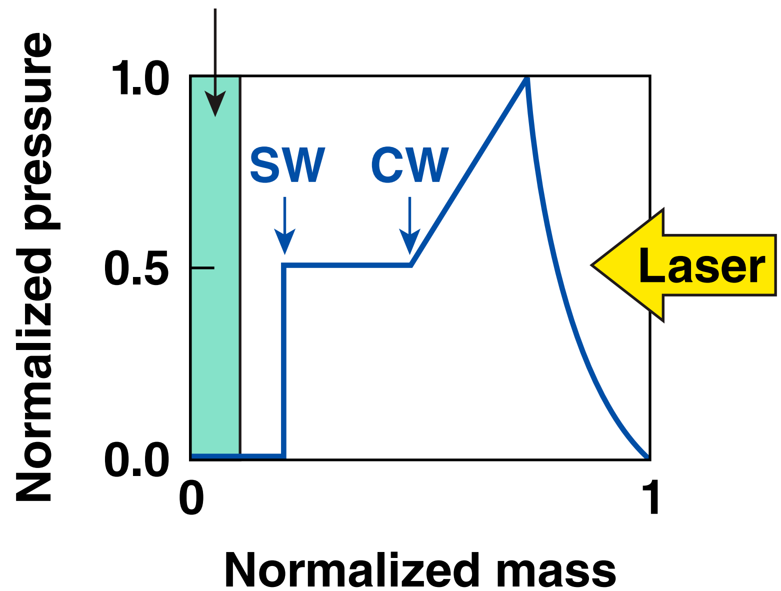
V. A. Smalyuk *et al.*, Phys. Rev. Lett. 101, 025002 (2008).
V. A. Smalyuk *et al.*, Phys. Plamas 15, 082703 (2008).

The initial ignition designs use a shock wave and isentropic compression to reach the areal density required for ignition

- Accurate shock- and compression-wave timing sets the proper α_{in}, $\rho R \sim \alpha_{in}^{-0.6}$.*



CW and SW must coalesce near the inner edge of the shell

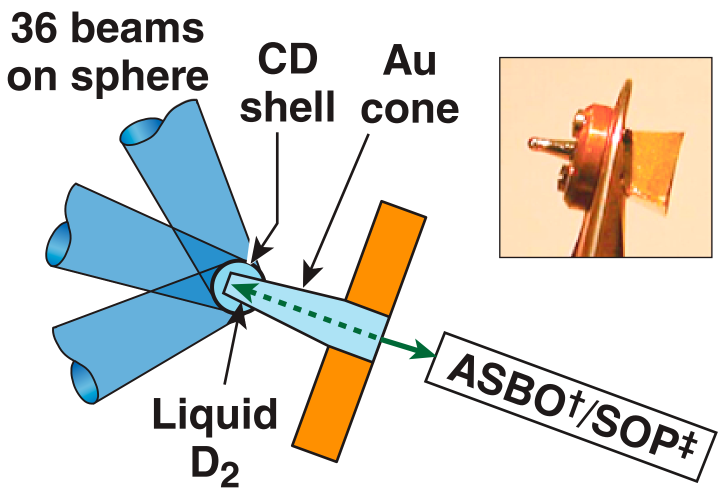


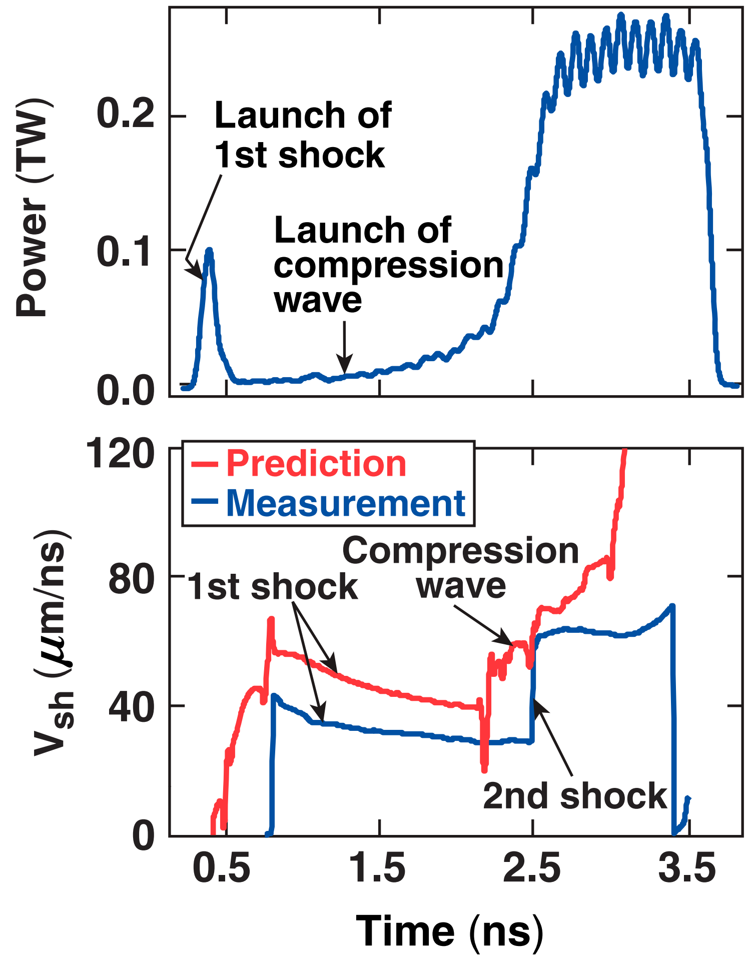
*R. Betti and C. Zhou, Phys. Plasmas 12, 110702 (2005).
V. N. Goncharov *et al.*, Bull. Am Phys. Soc. 52, 96 (2007), paper GI1 1.

TC7809c

Shock-velocity measurements indicate that the compression wave turns into a shock inside the shell

- A technique to time multiple shock waves was developed through the National Ignition Campaign*



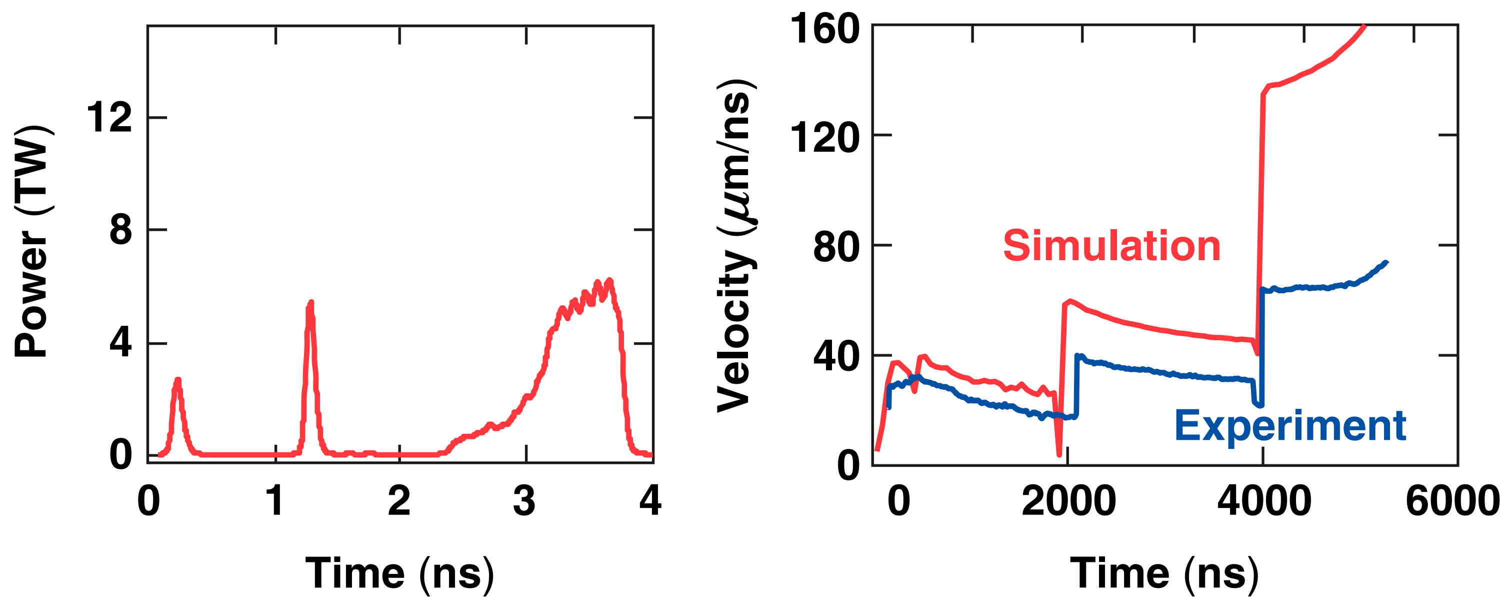


- Discrepancies between measured and predicted areal densities can be due to shock mistiming

*T. R. Boehly (QI1.00003).
†P. Celliers *et al*., Rev. Sci. Instrum. 75, 4916 (2004).
‡J. Oertel *et al*., Rev. Sci. Instrum. 70, 803 (1999).

E17449

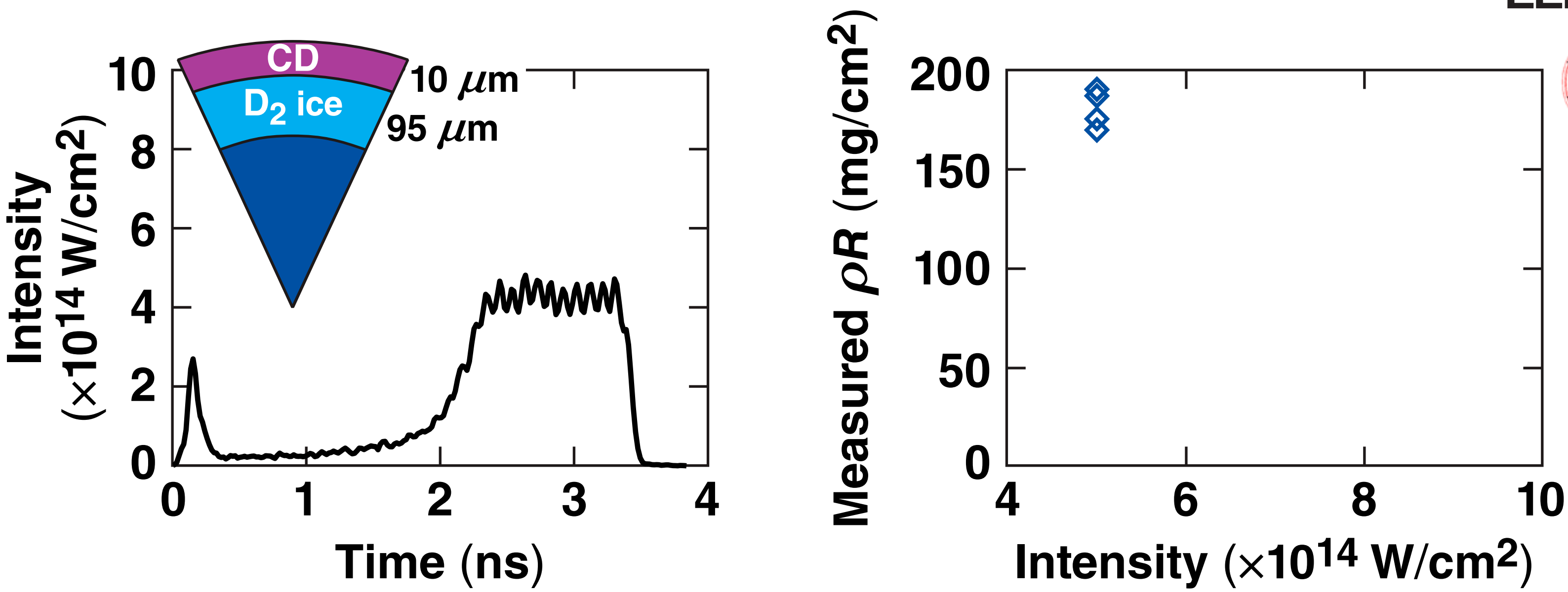
A multiple-shock-wave target design makes accurate timing experimentally possible*



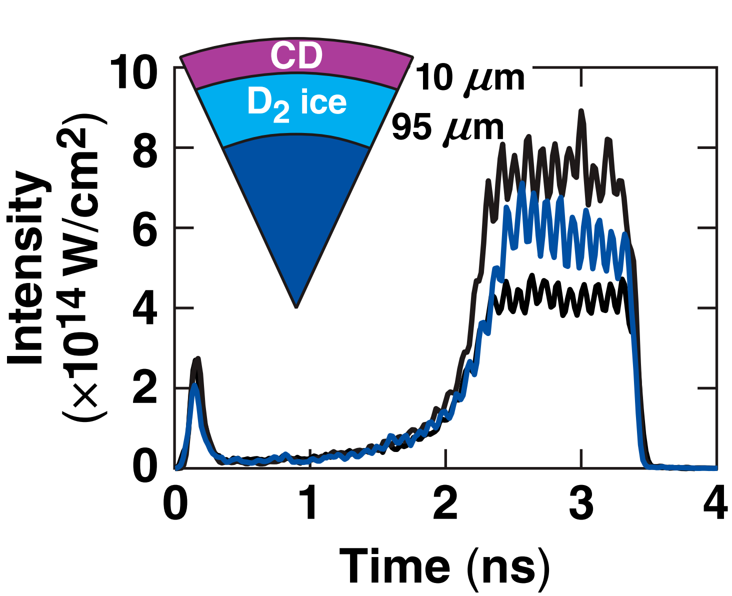
- Indirect-drive target designs use multiple shock waves**
- We are moving to a four-shock (triple-picket design)
- It is easier to experimentally time multiple shock waves

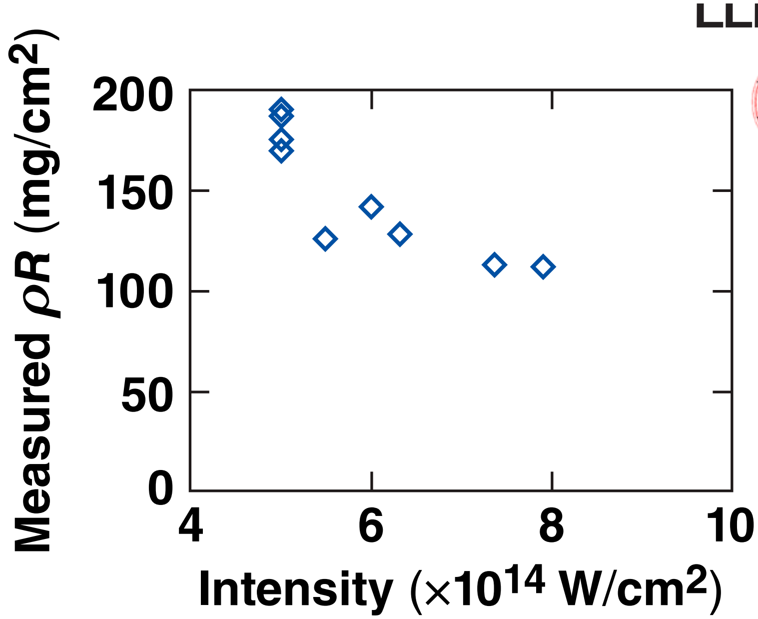
*T. R. Boehly *et al*., (QI1.00003)
** S. Haan *et al*., Fusion. Sci. Tech. 49, 553 (2006).

Ignition-relevant areal densities were achieved at peak intensities of ~5×10^{14} W/cm^2



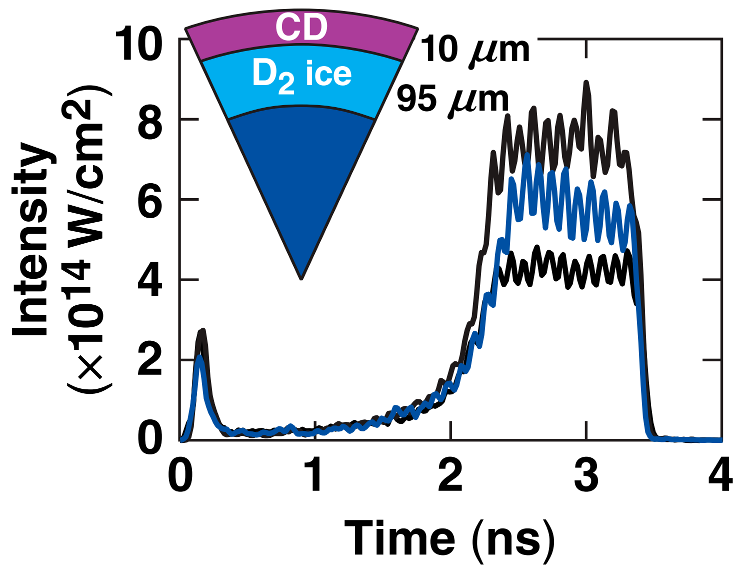
The compression is reduced as peak intensity increases

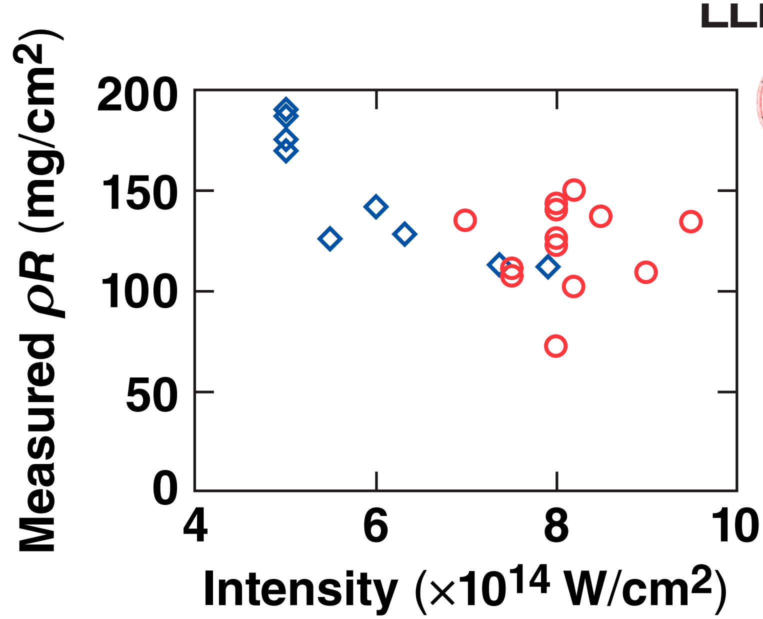


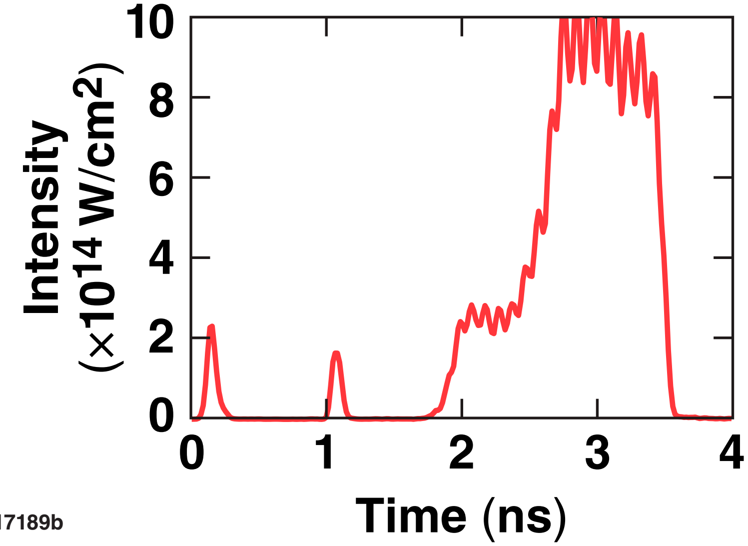


E17189a

Better-tuned double-picket pulses improve measured areal density at peak intensities of ~10^{15} W/cm^2







E17189b

Introduction of a third picket relaxes the requirement for main pulse shaping

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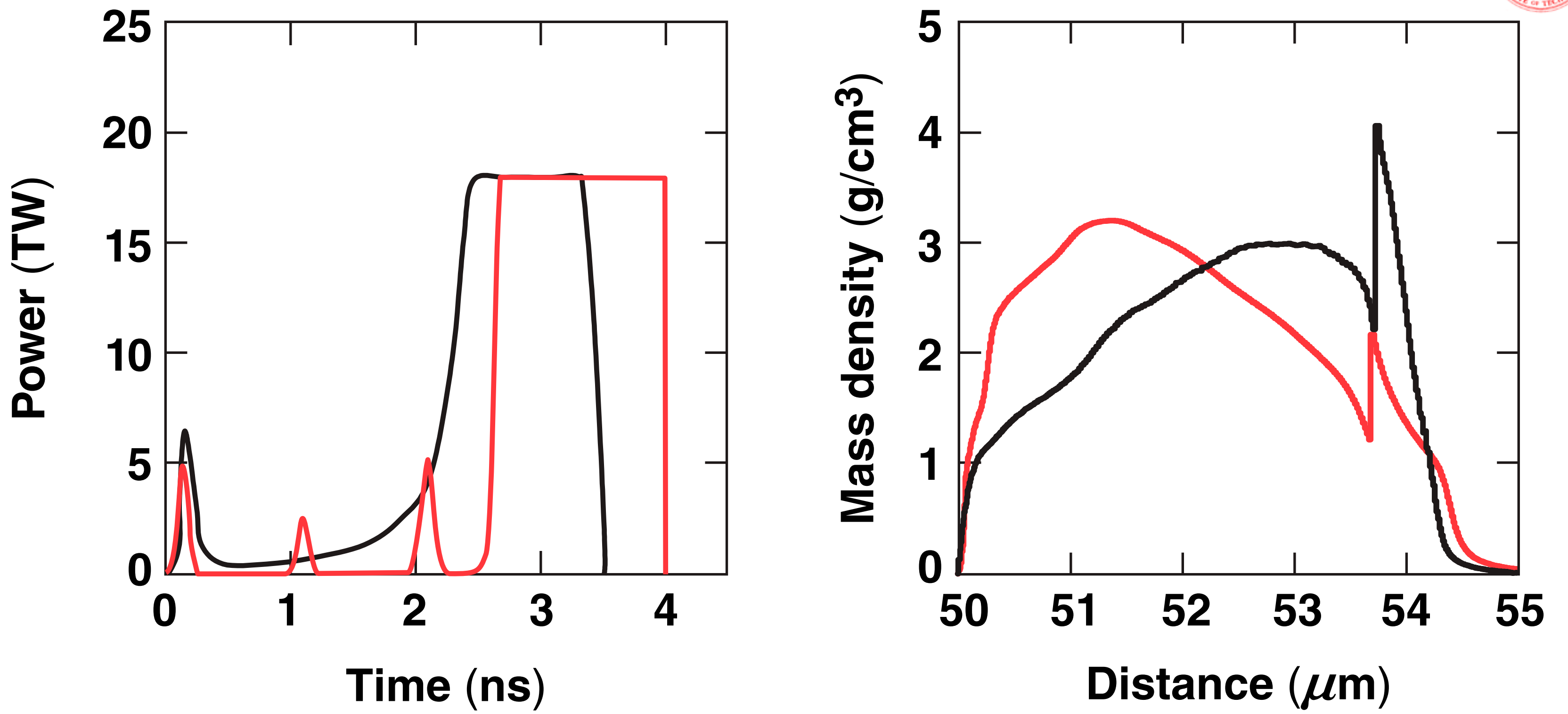

Adiabat is steeper inside the shell in triple-picket design

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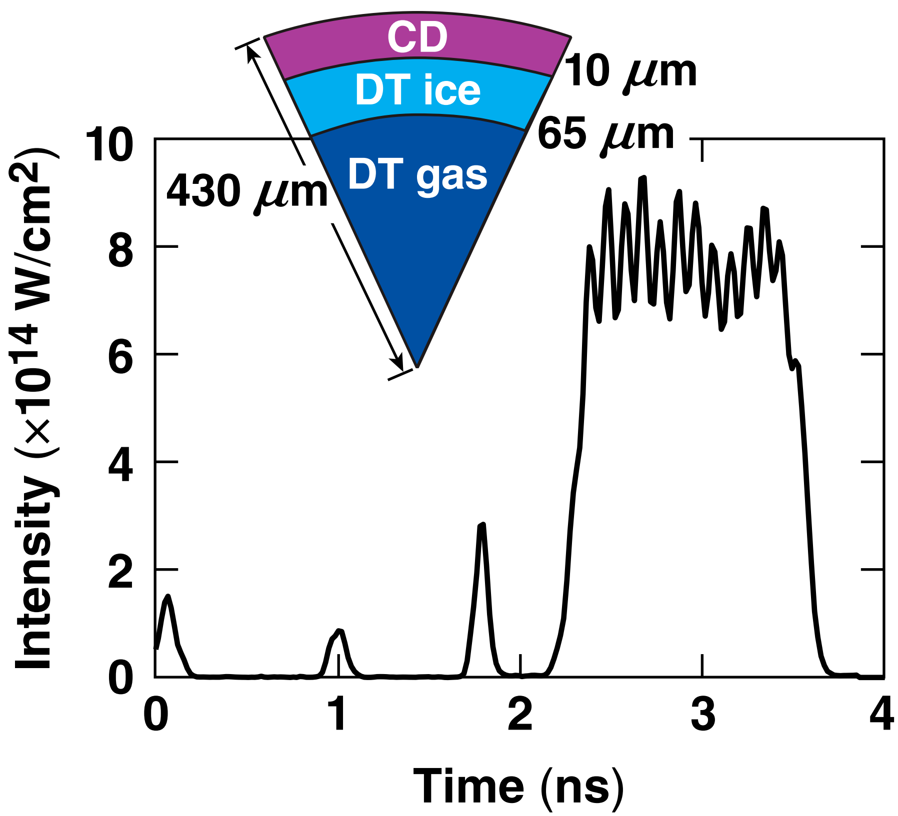
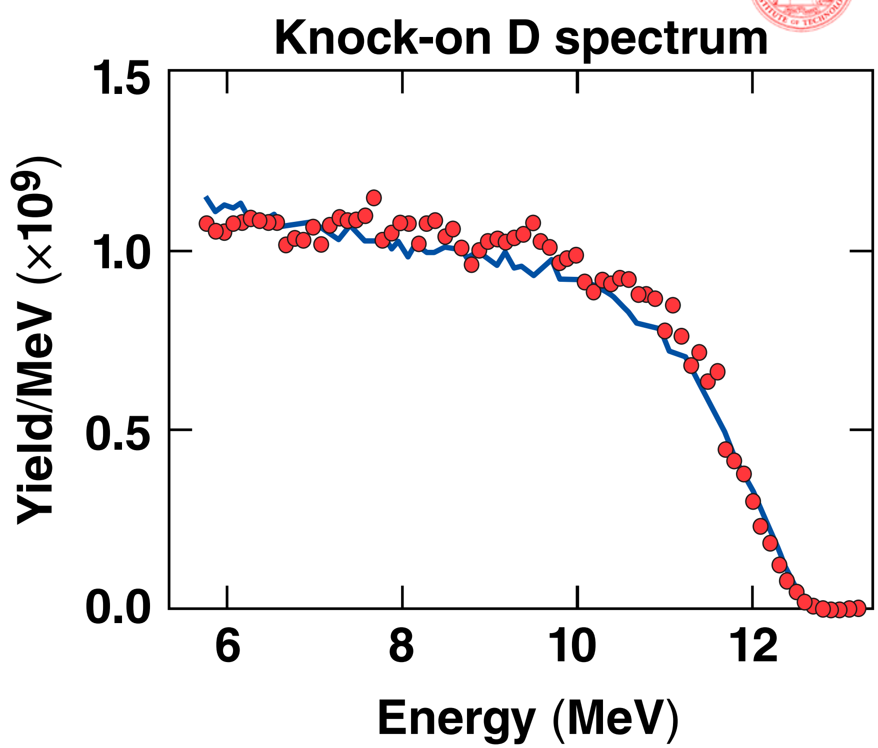
A triple-picket-pulse implosion produced a ρR of ~200 mg/cm^2 with a 65-μm DT ice target at a high-implosion velocity, ~3 × 10^7 cm/s





- The fit to experimental data indicates a ρR ~197±20 mg/cm^2 measured in one direction by a magnetic recoil spectrometer.
- The hard x-ray signal was low, ~100 pC.

E17451

Hot-electron signal increases with peak intensity, but is reduced in double-picket pulses

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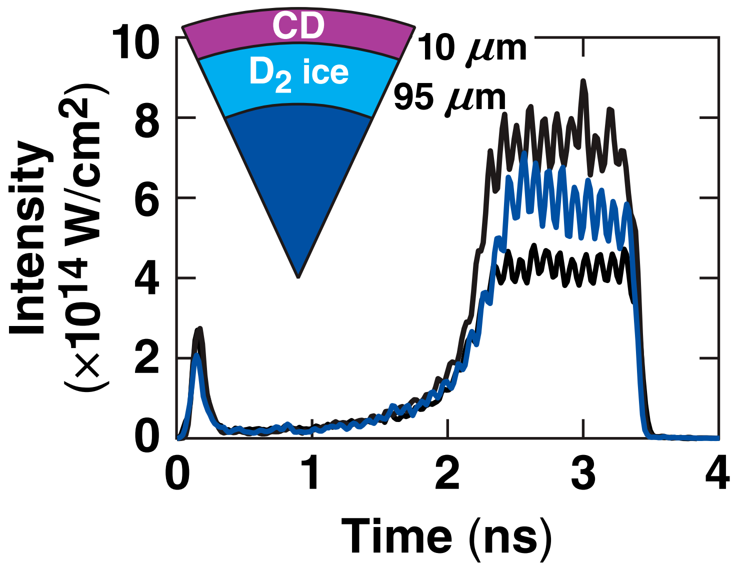
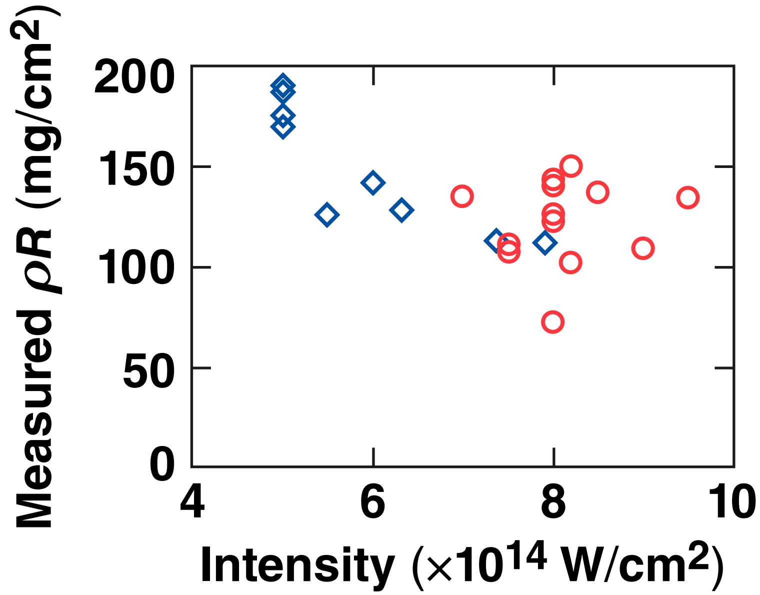
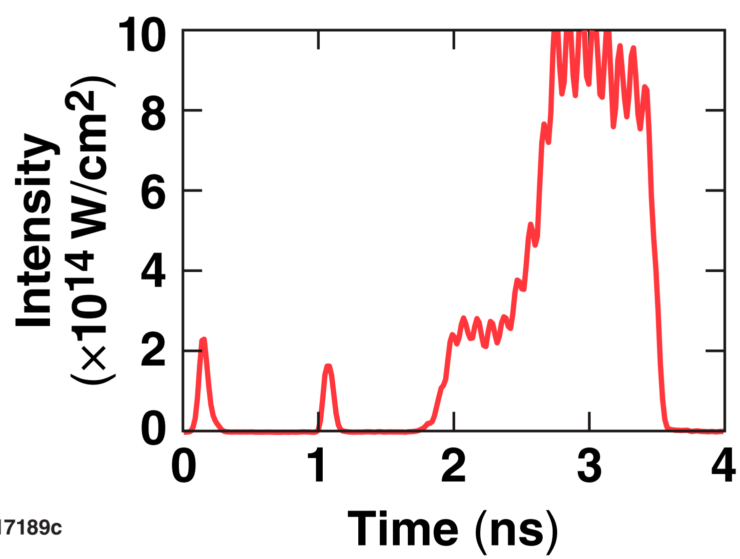
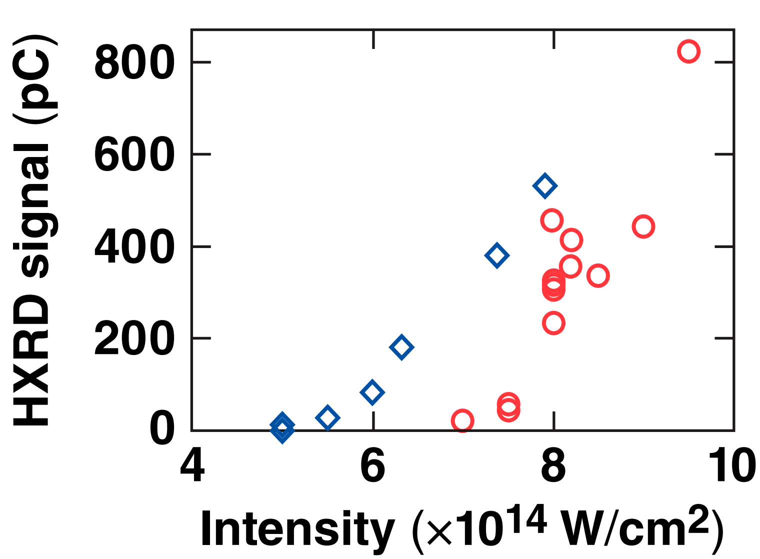


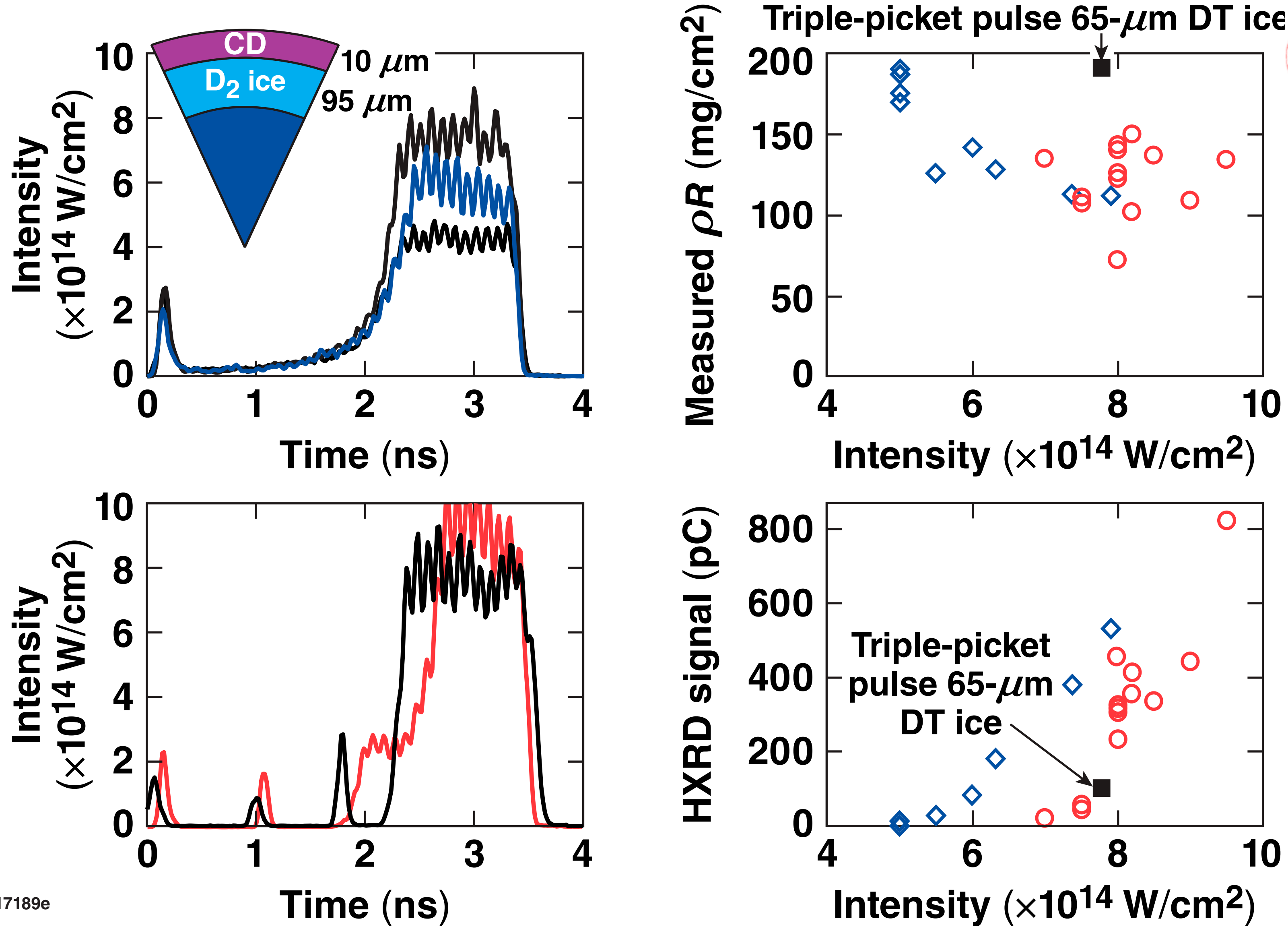






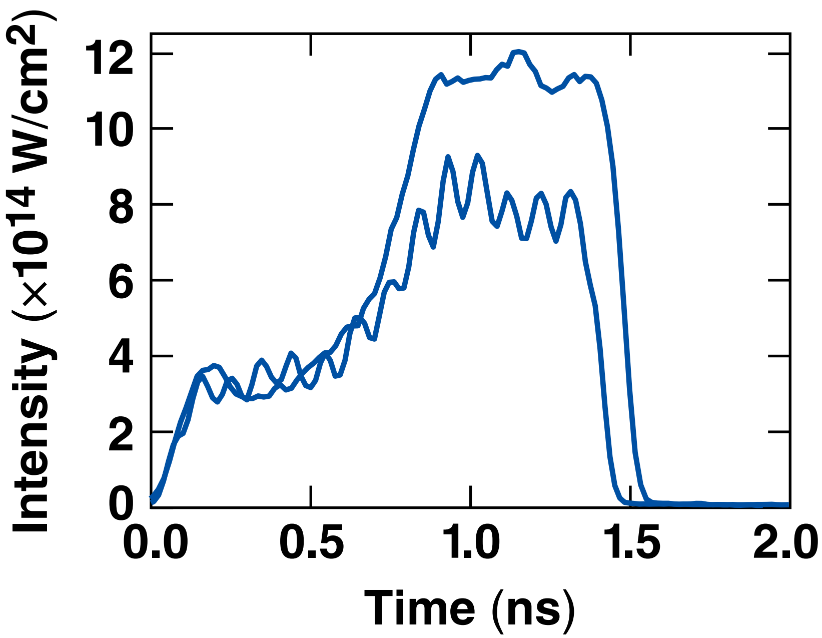
E17189c

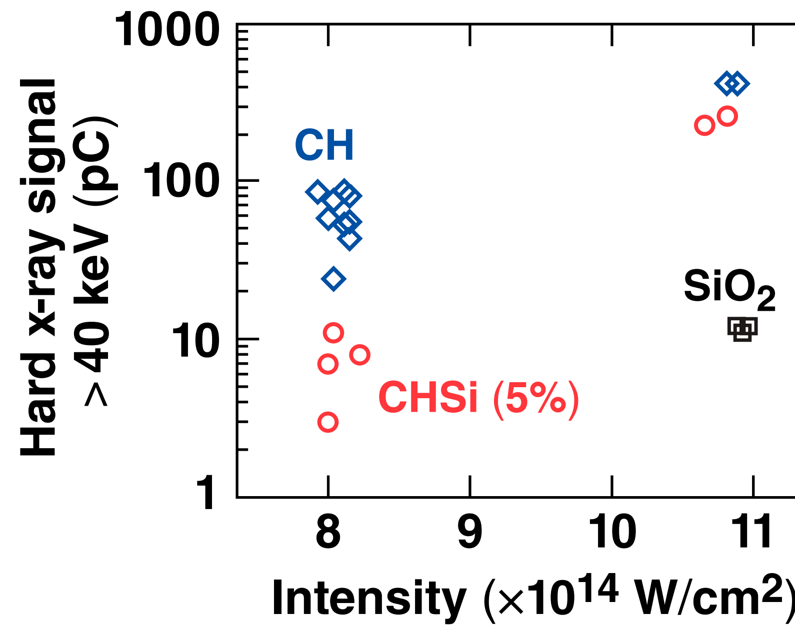
Hot-electron signal increases with peak intensity, but is reduced in double- and triple-picket pulses



E17189e

The hard x-ray signal is reduced by ~40× in SiO_2 ablators compared to CH ablators



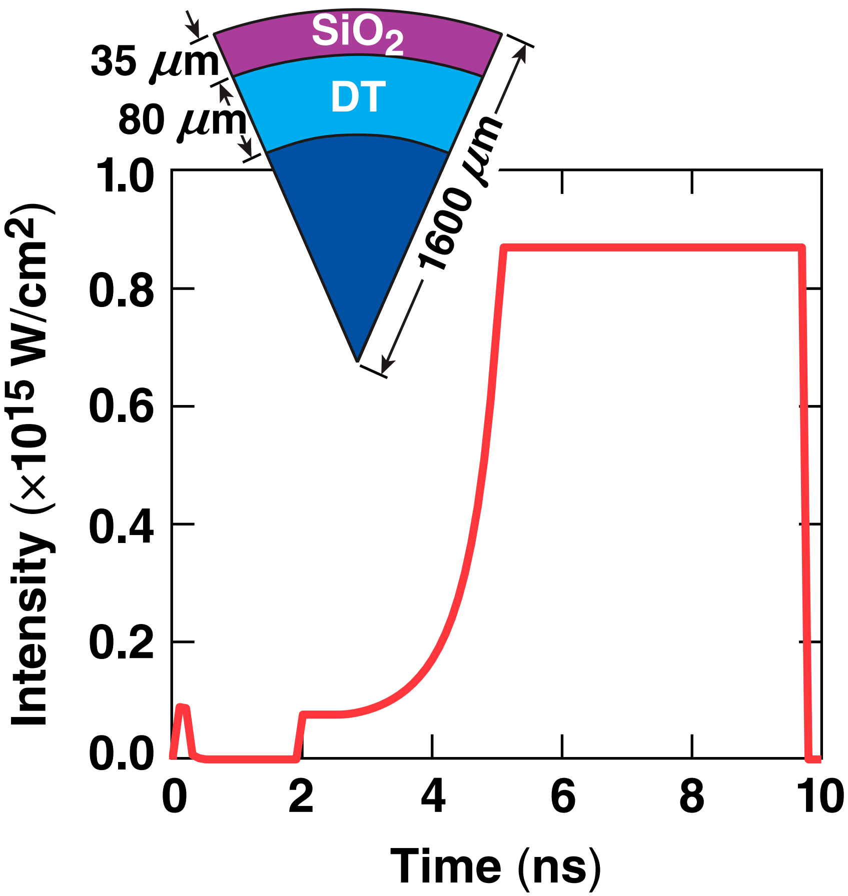


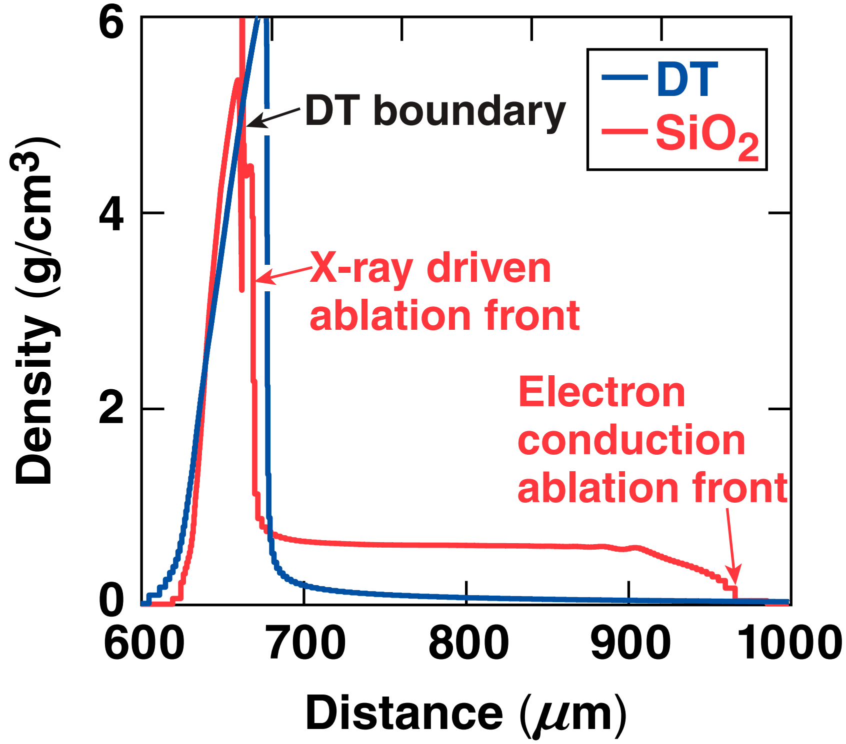
V. A. Smalyuk *et. al.*, submitted to Phys. Rev. Lett.

High-Z Ablator

High-Z ablators develop double ablation fronts;* the in-flight thickness is large → low IFAR

Ignition design for the NIF, Energy 1.5 MJ, Gain = 27





E17186

*S. Fujioka *et. al.*, Phys. Rev. Lett. 92 195001 (2004).

Summary/Conclusions

The understanding of cryogenic target implosions is essential to acheiving ignition on the NIF

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- Recent OMEGA experiments have demonstrated ignition-relevant areal densities at intensities of $\sim 5 \times 10^{14}$ W/cm^2.
- Higher implosion velocities require an intensity of $\sim 1 \times 10^{15}$ W/cm^2, previously shown areal density degredation.
- Three- and four-shock coalescence is being investigated for better adiabat control in cryogenic targets.
- High *Z* ablators significantly reduce hot-electron preheat.

Significant progress is being made in understanding high intensity cryogenic target implosions.

High-Z Ablator

Soft x-ray production in glass implosions is slightly below 1-D predictions

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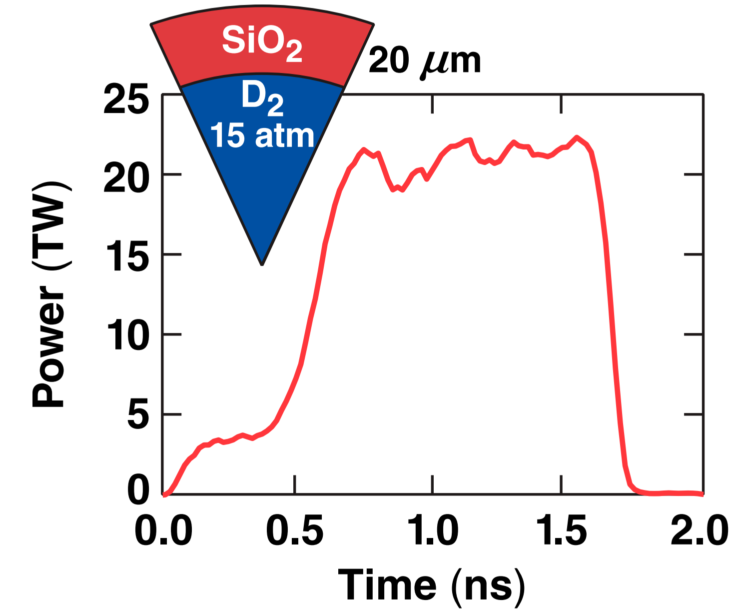

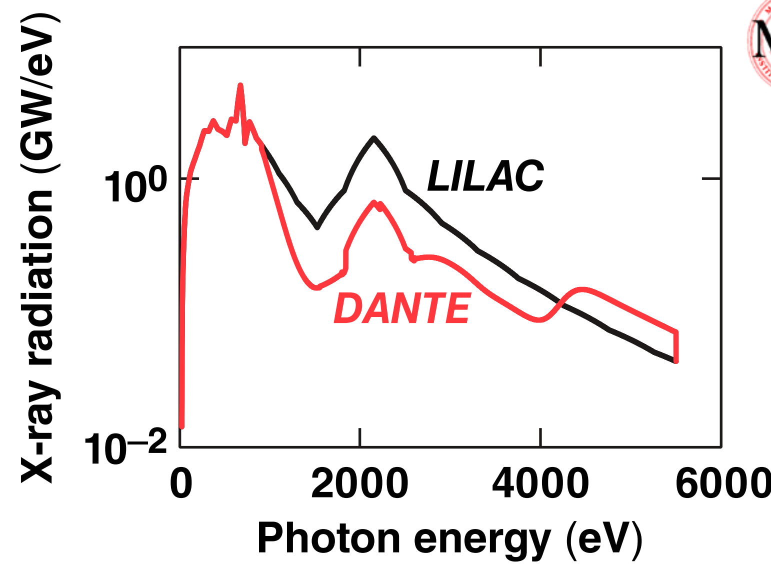

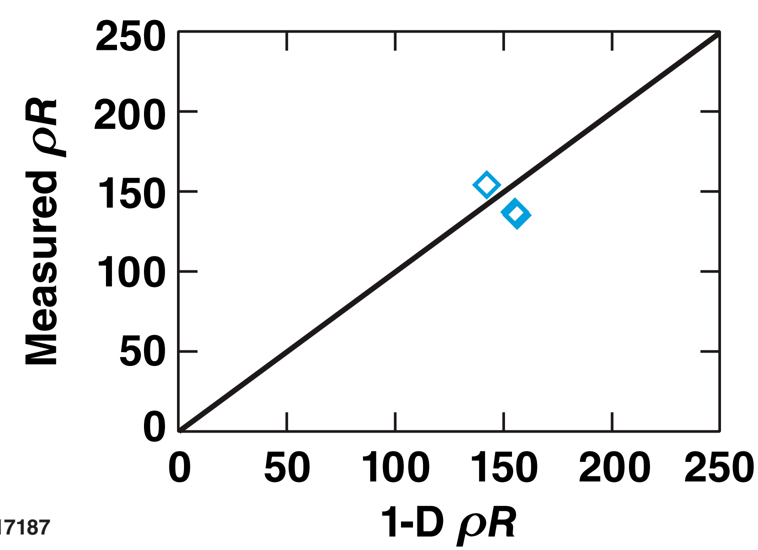

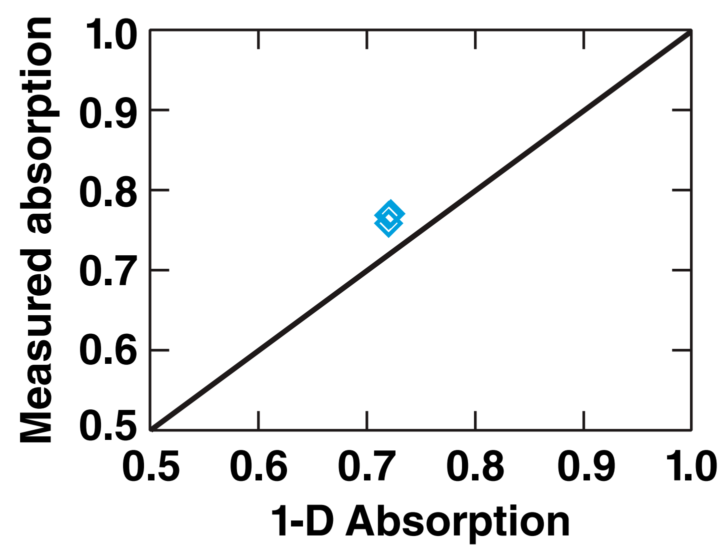

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