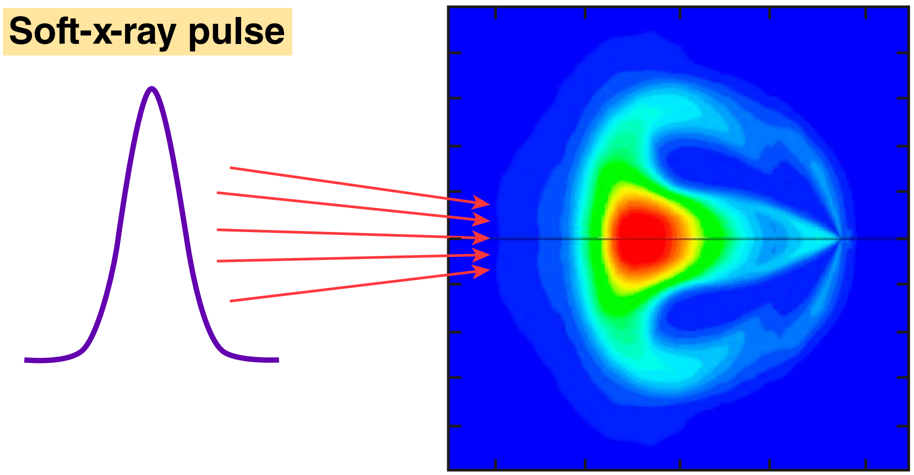
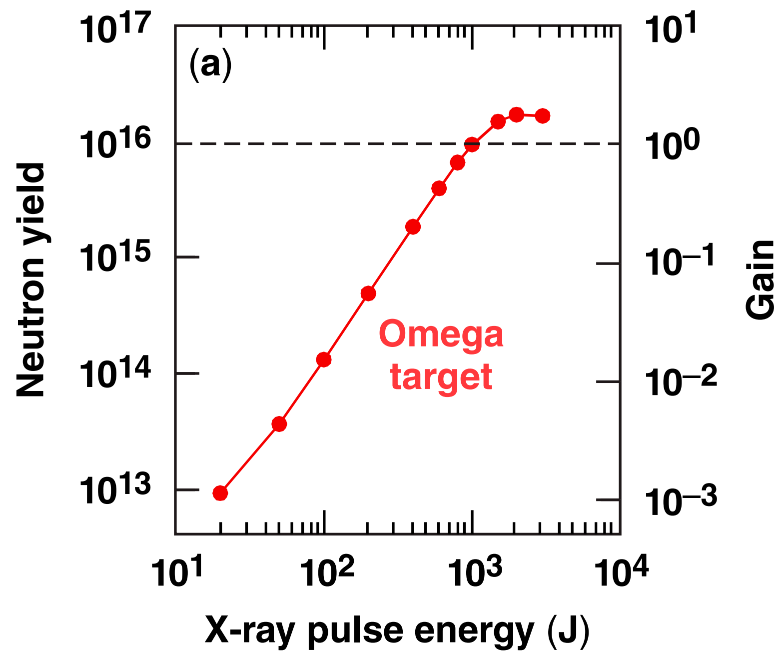
Burning DT Plasmas with Ultrafast Soft X-ray Pulses





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- Fast ignition with soft x-ray flashing has been investigated for high-density deuterium–tritium (DT) plasmas assembled on OMEGA and the NIF, using 2-D *DRACO* simulations
- Coherent soft x-ray sources with $h\nu = 500$-eV photons are efficient for igniting dense DT plasmas
- Burning plasma conditions are predicted on Omega with 200 to 500 J energy for: *10-ps soft x-ray pulse, $h\nu = 500$ eV, focused into a 10-μm spot*

*S. X. Hu, V. N. Goncharov, and S. Skupsky, Phys. Plasmas 19, 072703 (2012).

Collaborators

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X-ray fast ignition (XFI)* was proposed to use hard x-rays ($h\nu$ = 3 to 6 keV) from "fourth generation" synchrotrons

<u>Advantages of XFI:</u>

- The heating source can be separated from the dense-plasma assembly for better implosion integrity
- The heating x-ray pulse energy can be delivered directly to the dense DT plasma regions
- X-ray pulse energy can be more easily propagated through plasmas than charge particles
- The energy requirement for XFI can be orders of magnitude lower than other FI schemes because of its "layer-by-layer" heating mechanism

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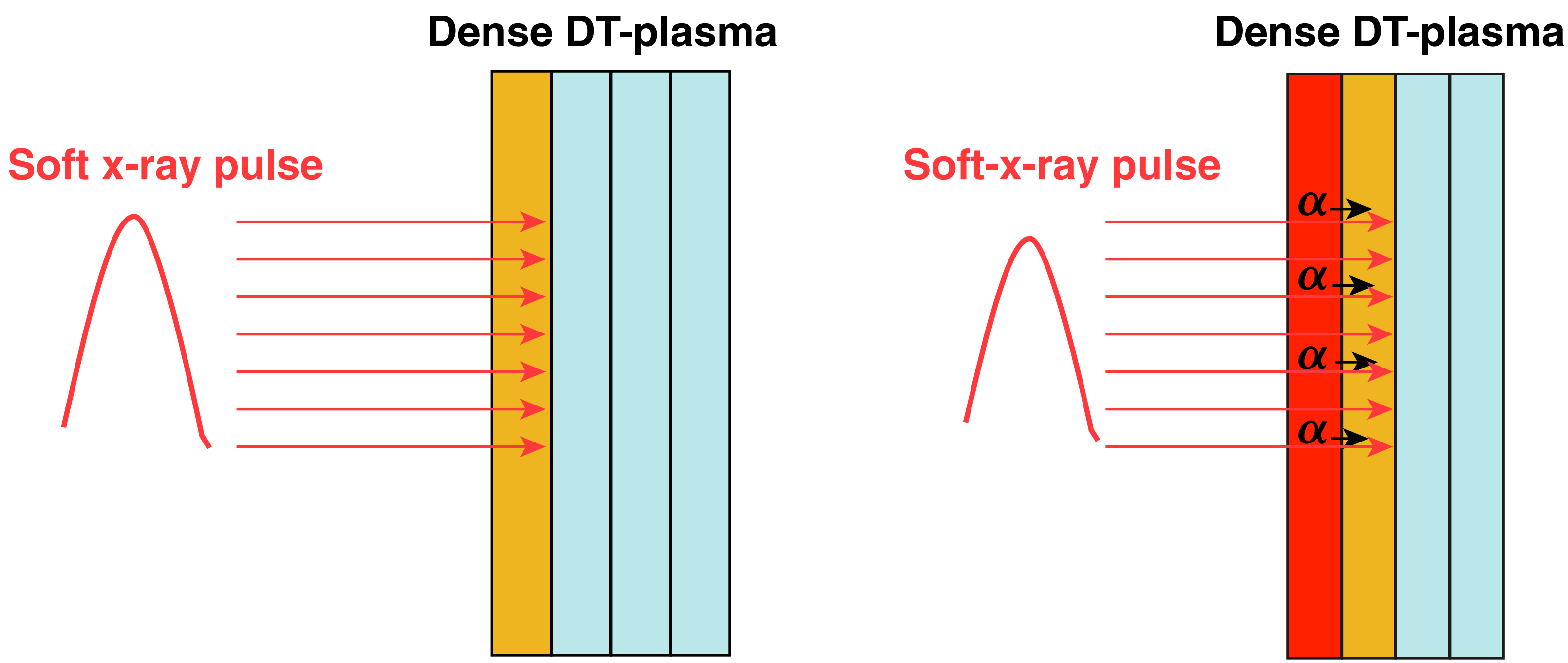
*V. Shlyaptsev and R. Tatchyn, Proc. SPIE 5194, <u>30</u> (2004).

The unique "*layer-by-layer*" heating of soft x rays reduces the energy requirement for plasma burning



<u>Soft x-rays ($h\nu$ = 500 eV) favor "layer-by-layer" heating</u>

- For ρ = 100 g/cm^3 and T = 200 eV, penetration distance $D \simeq$ 0.4-μm
- For ρ = 100 g/cm^3 and T = 5 eV, penetration distance $D \simeq$ 4.7-μ

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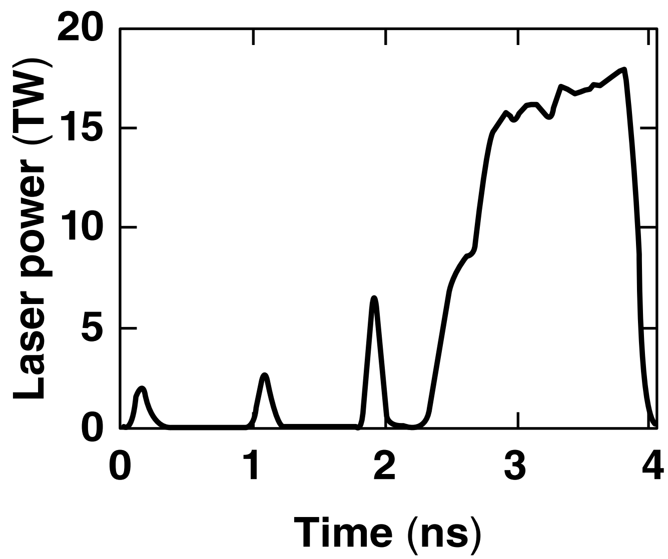
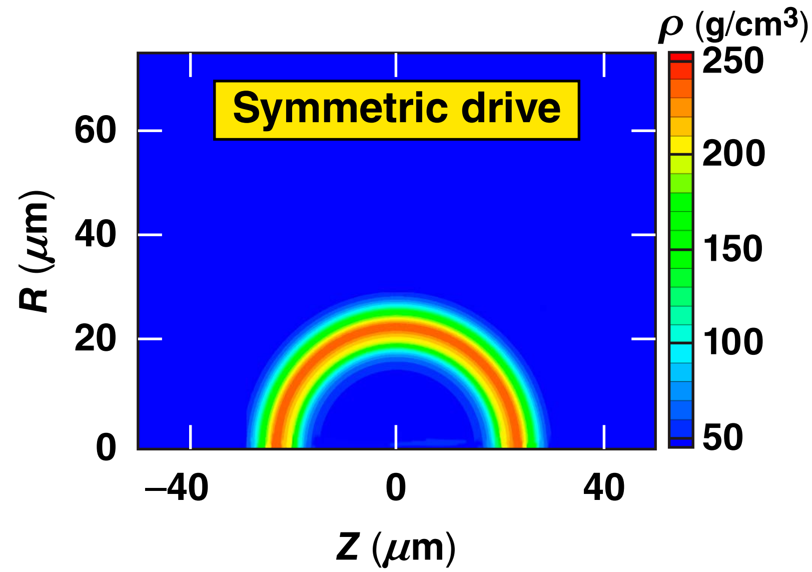
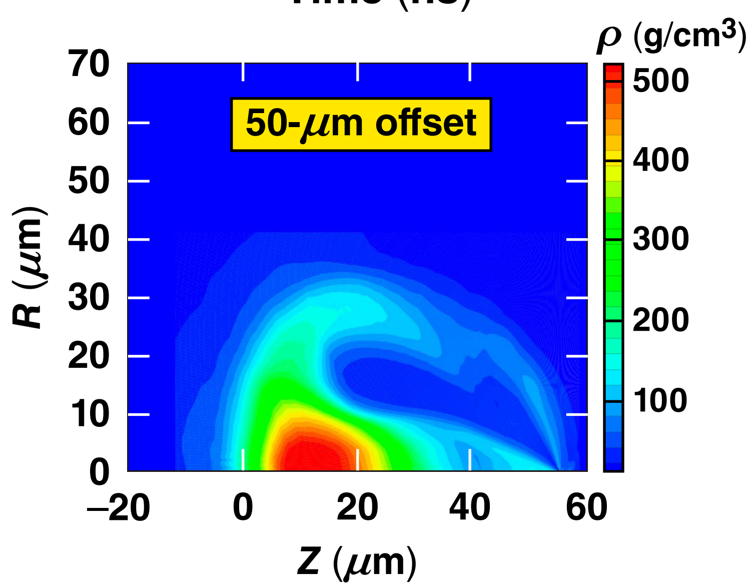
Higher-density DT plasmas for fast ignition can be assembled by intentionally offsetting the target





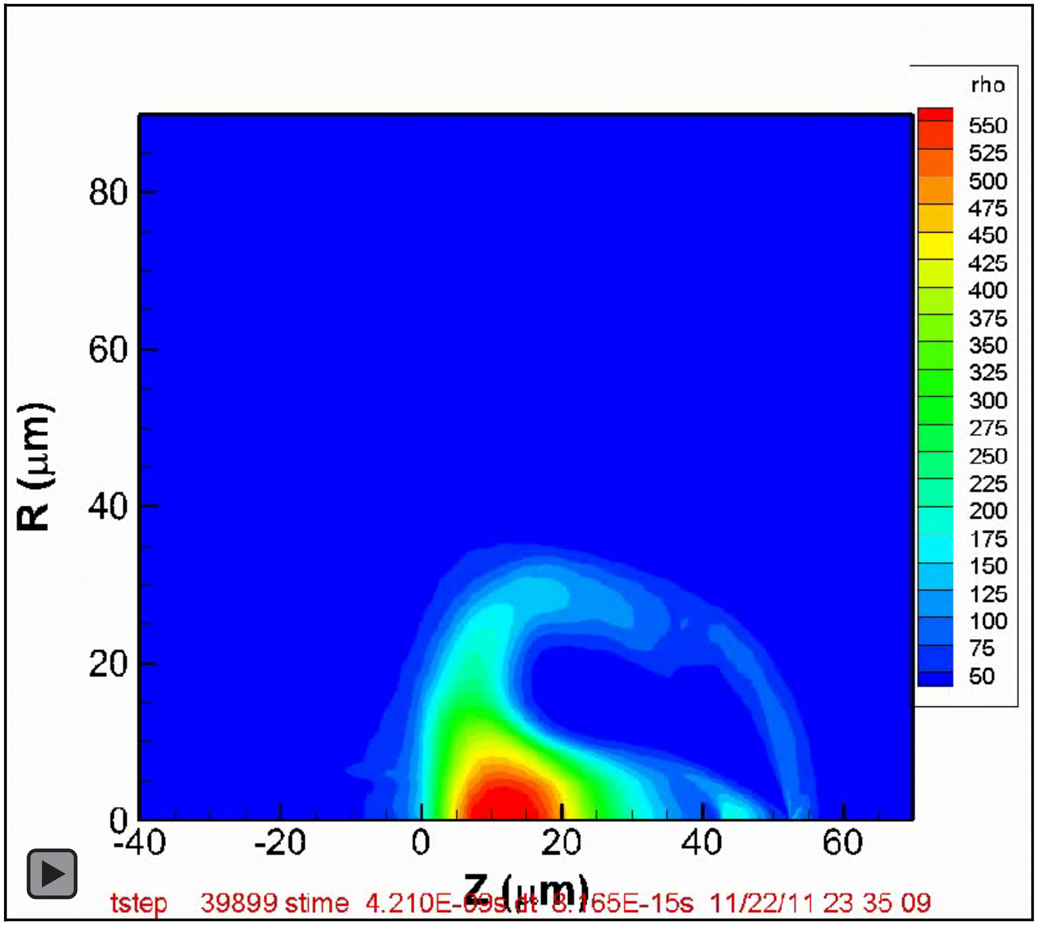


Asymmetric ρR distributions have been seen in MRS measurements* on OMEGA for large-offset shots.

TC10166

*J. A. Frenje *et al*., Phys. Plasmas 16, 042704 (2009).

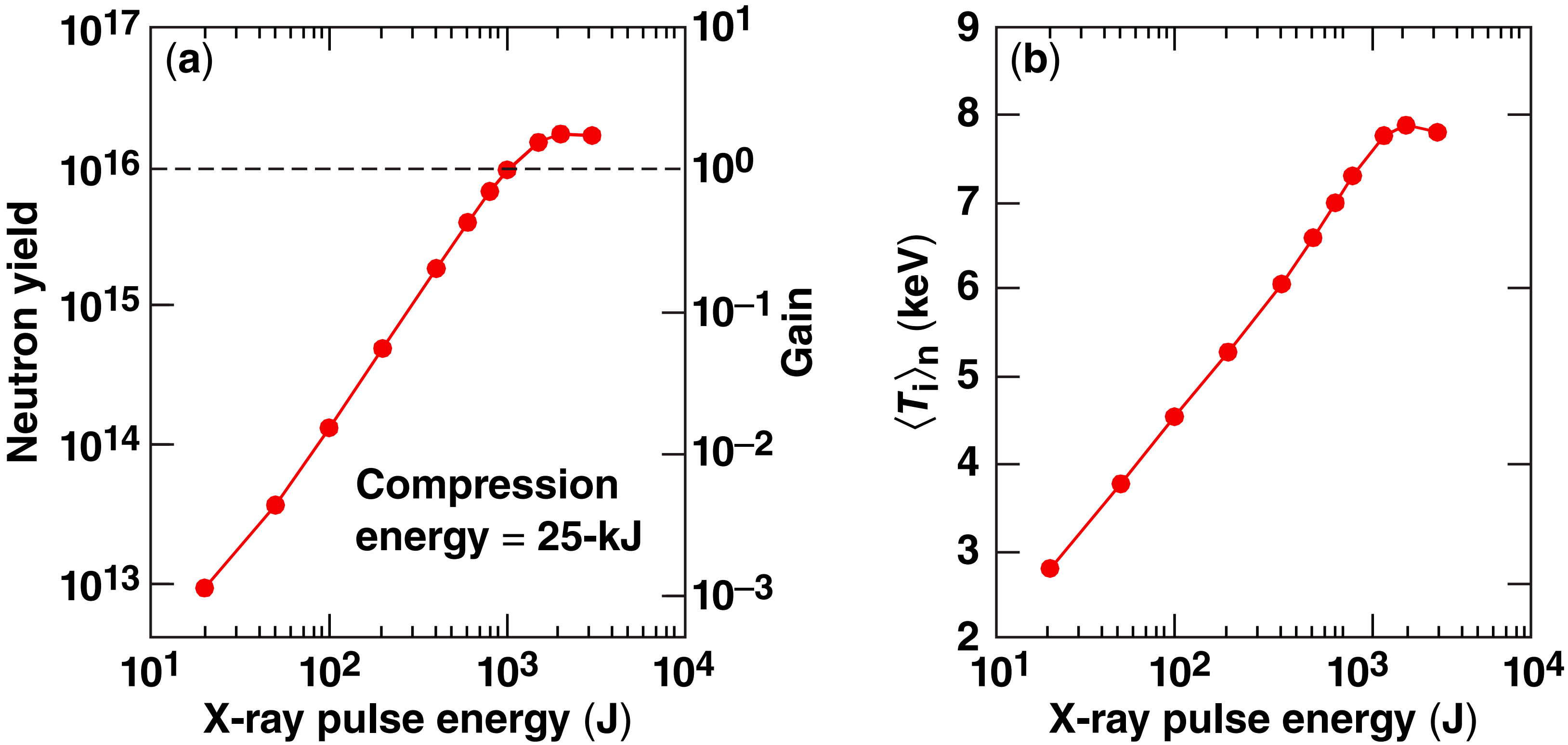
DT plasma burning with soft x-ray pulse towards *breakeven* is illustrated in *DRACO* simulations



<u>Soft x-ray pulse</u>: 10 ps, $h\nu$ = 500 eV, 1 kJ focusing into 10-μm spot

<u>DT-burning results</u>: $Y = 9.43 \times 10^{15}$, $\langle T_i \rangle_n$ = 7.2-keV, gain = 1.08

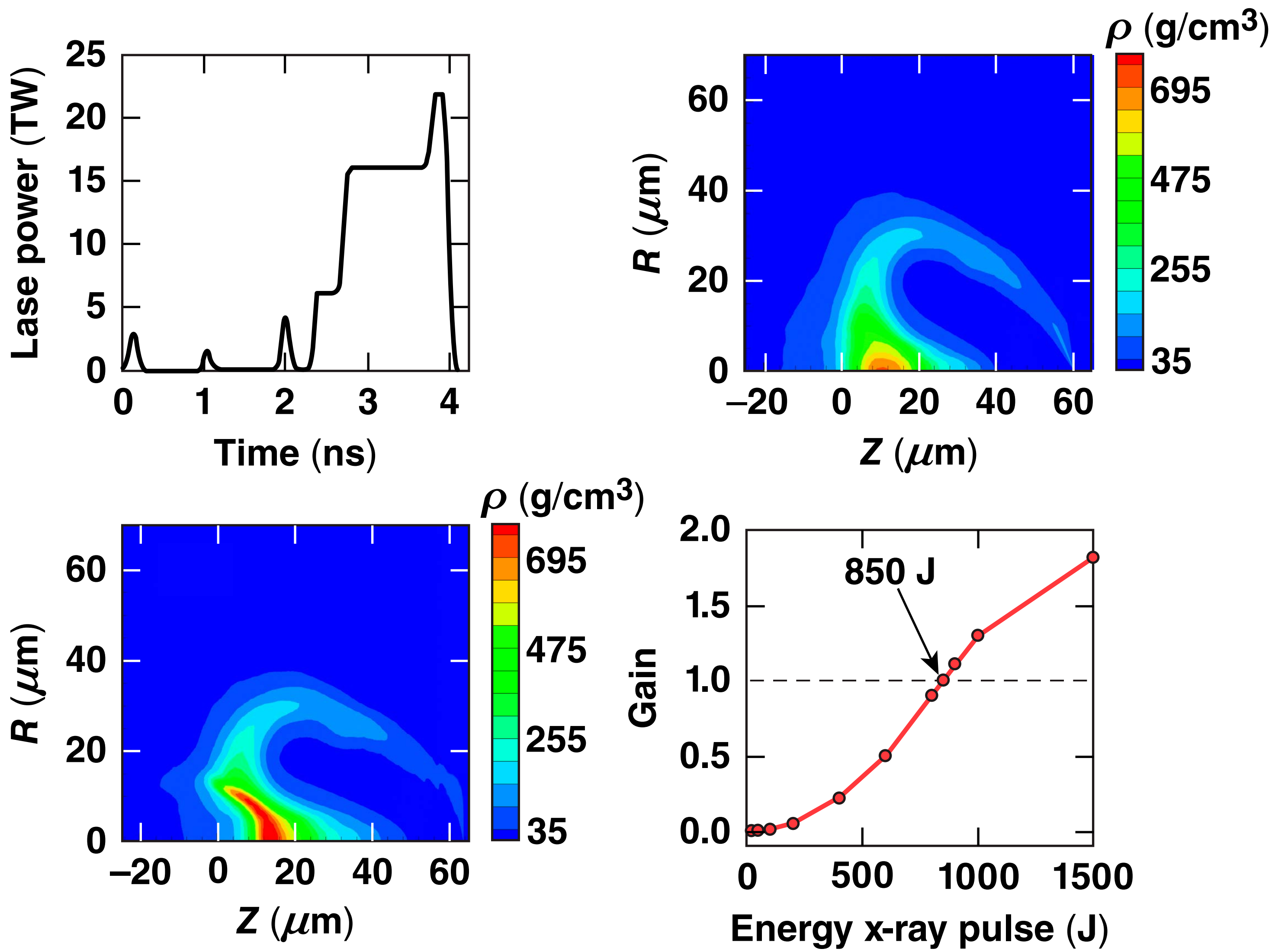
Scanning the soft x-ray pulse energy, the *break-even* threshold is found to be around ~1 kJ for this Omega design*



TC10168

*S. X. Hu, V. N. Goncharov, and S. Skupsky, Phys. Plasmas 19, 072703 (2012).

The energy requirement for SXFI could be further reduced by using high-compression pulse shapes



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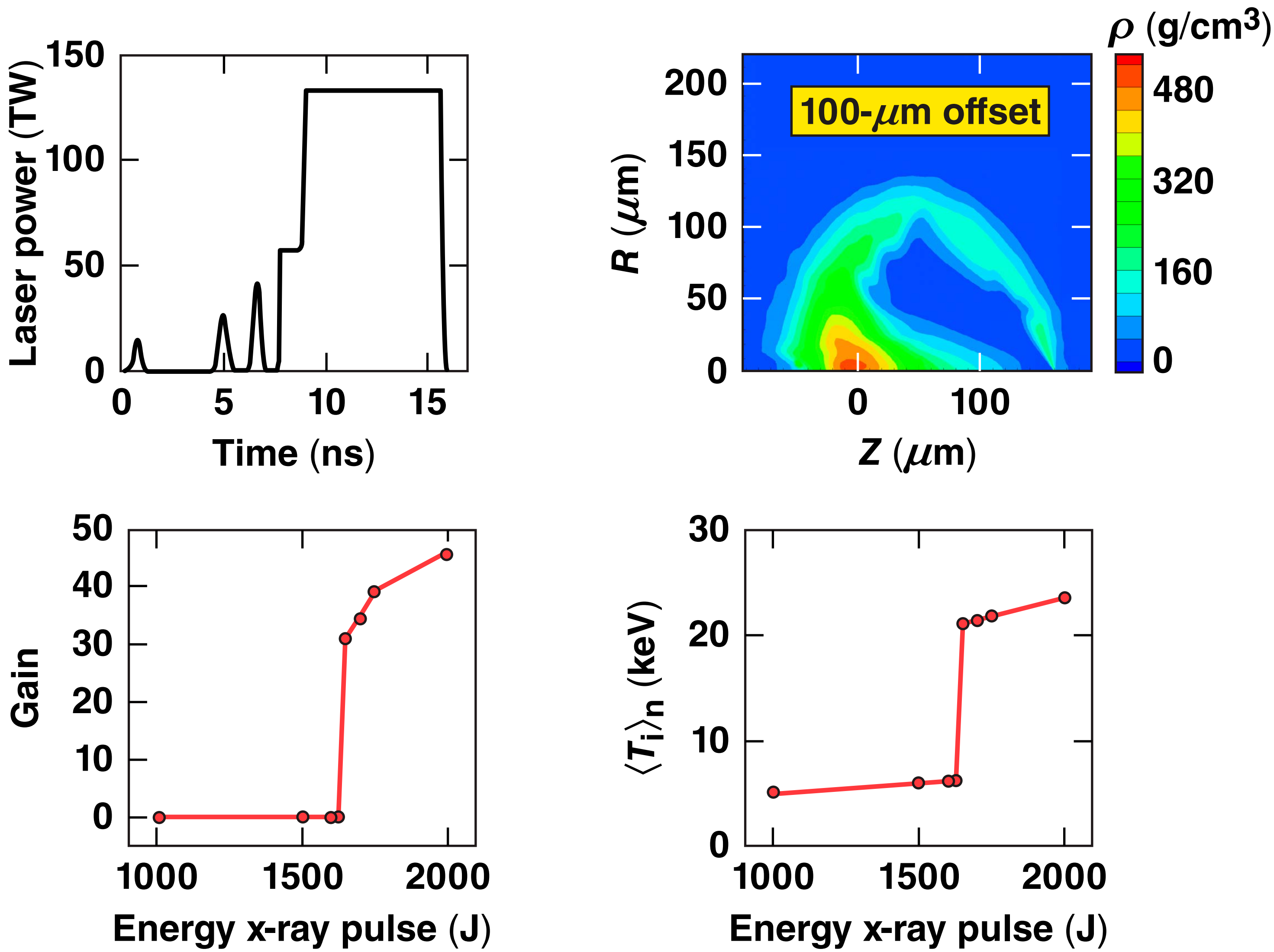
Scaling the idea of SXFI to a 1-MJ NIF target, gains above ~30 can be obtained with 1.65-kJ soft x rays



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Ways to generate such powerful soft x-ray sources remain to be explored

- Coherent XUV and soft x-ray radiations can be generated from an intense IR-pulse reflection off a relativistic flying mirror (plasma wave)*, frequency upshift by ~$4\gamma^2$
- Tunable radiation may be generated from laser-pulse reflection from an ionization front**
- Coherent synchrotron emission (harmonics) in the transmission direction can be produced from relativistic intense laser-thin-foil interactions***
- X-ray lasers or fourth-generation synchrotrons?

*M. Kando *et al*., Phys. Rev. Lett. 103, 235003 (2009); S. V. Bulanov, T. Esirkepov, and T. Tajima, Phys. Rev. Lett. 91, 085001 (2003).
** W. B. Mori, Phys. Rev. A 44, 5118 (1991).
***B. Dromey et al., "Coherent Synchrotron Emission from Electron Nanobunches Formed in Relativistic Laser-Plasma Interactions," to be published in Nature Physics; D. an der Brügge and A. Pukhov, Phys. Plasmas 17, 033110 (2010).

Summary/Conclusions

Soft x-ray fast ignition* (SXFI) has been proposed for igniting DT plasmas assembled on OMEGA and the NIF

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