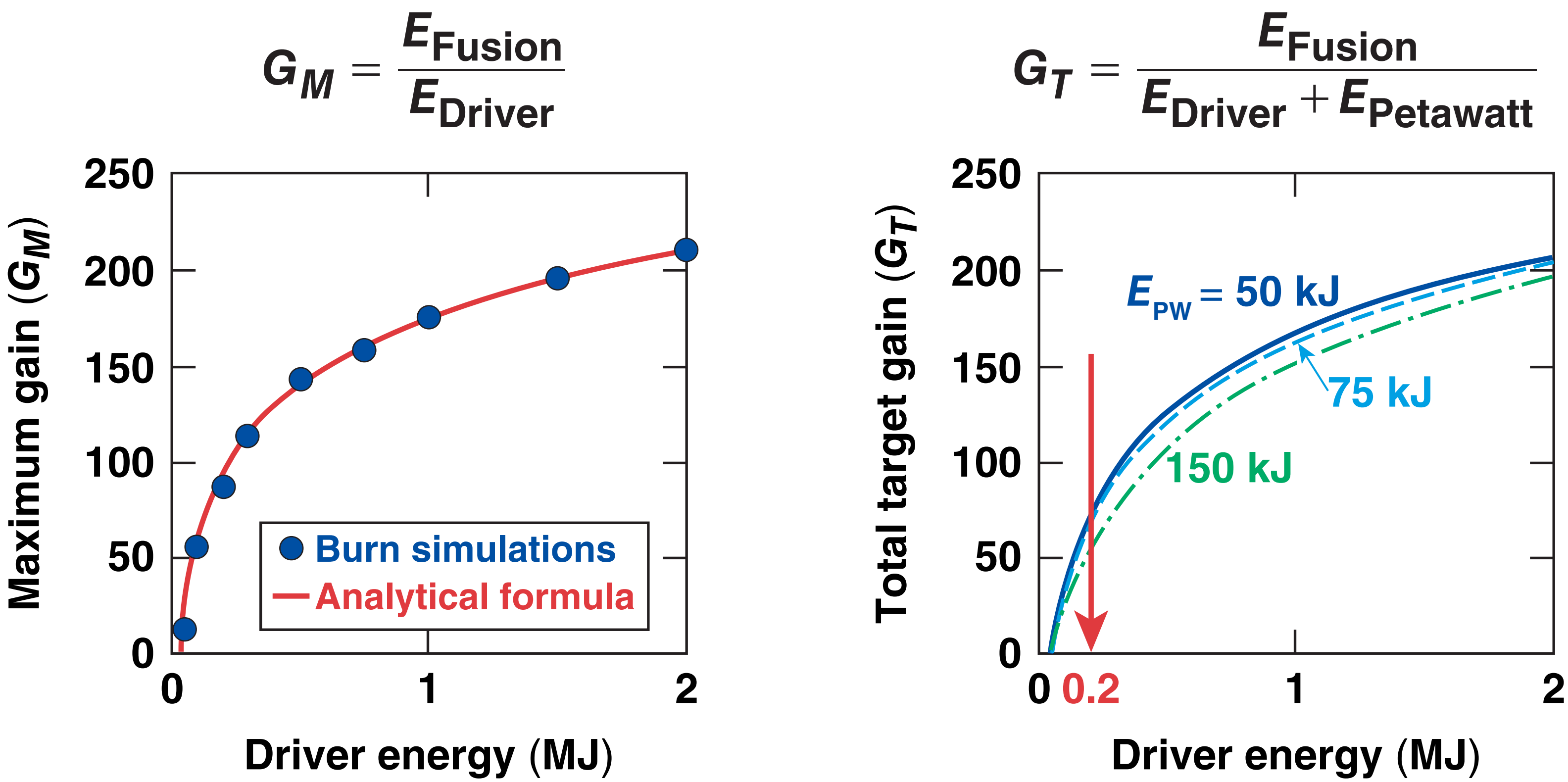
Gain Curves for Fast-Ignition Inertial Confinement Fusion



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Summary

Gain curves for fast-ignition and ignition requirements have been obtained from hydrodynamic simulations of realistic high-gain, fast-ignition targets

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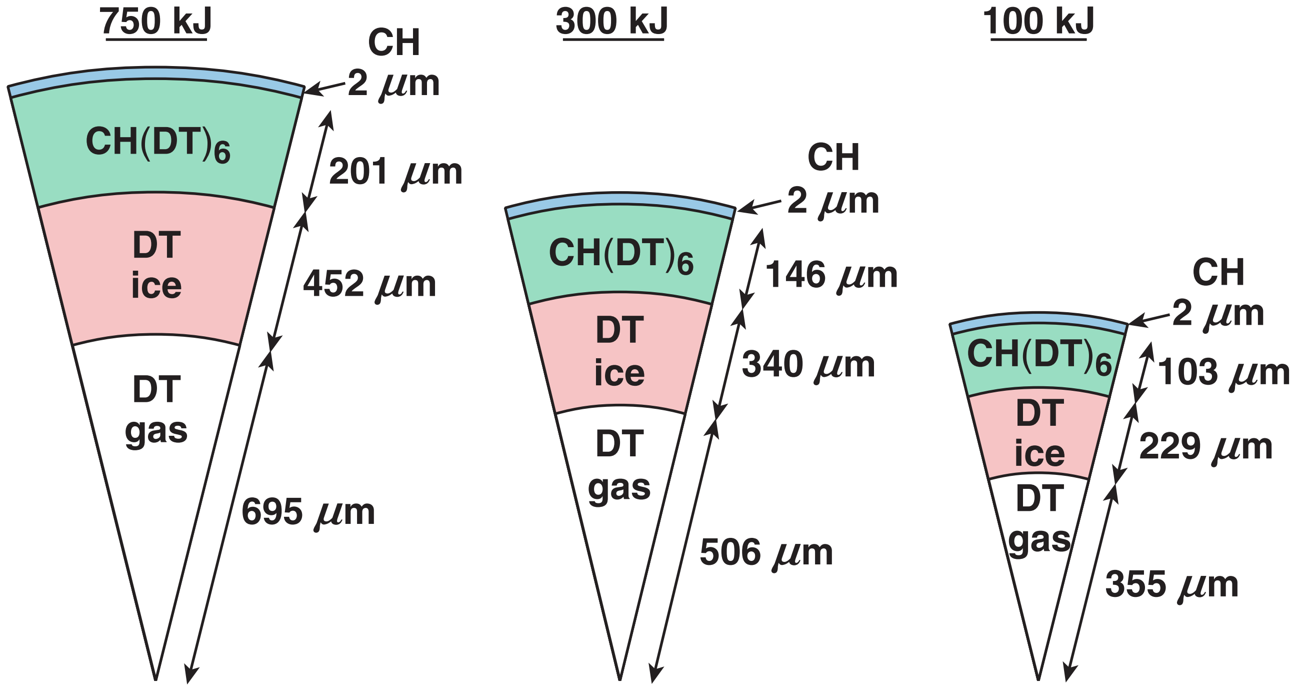
- Simulations use high-density and high-ρR fuel assembly recently suggested for fast ignition.*
- A maximum gain curve has been generated for ignition by a collimated monoenergetic electron beam.
- Simulations using Gaussian laser pulses and ponderomotive temperature scaling for fast electrons predict a minimum laser energy for ignition ≥100 kJ for $\lambda_L = 1.05\ \mu$m.
- A shorter laser wavelength might be necessary to reduce the range of fast electrons to the fuel core size and lower the ignition energy.

TC7616

*R. Betti and C. Zhou, Phys. Plasmas 12, 110702 (2005).

Implosion of the high-density and high-ρR fuel assembly[1] was simulated using the one-dimensional hydrocode *LILAC*[2]



- Massive cryogenic shells can be imploded with a low-implosion velocity on a low adiabat using a relaxation-pulse technique.[3]
- Such targets are practically unperturbed by the Rayleigh–Taylor instability justifying 1-D simulation of the implosion.

[1]R. Betti and C. Zhou, Phys. Plasmas 12, 110702 (2005).
[2]J. A. Delettrez *et al.*, Phys Rev. A 36, 3926 (1987).
[3]R. Betti *et al.*, Phys. Plasmas 12, 042703 (2005).

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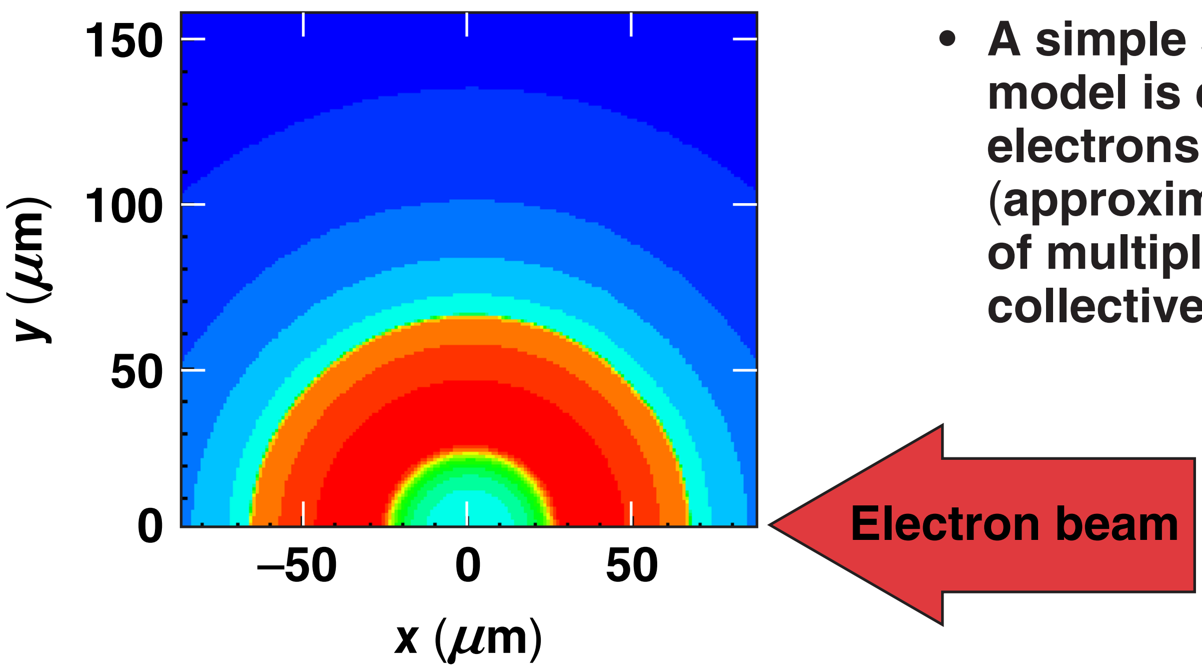
The two-dimensional, two-fluid hydrocode *DRACO*[1] has been recently modified[2] to include electron-beam energy deposition into the dense fuel



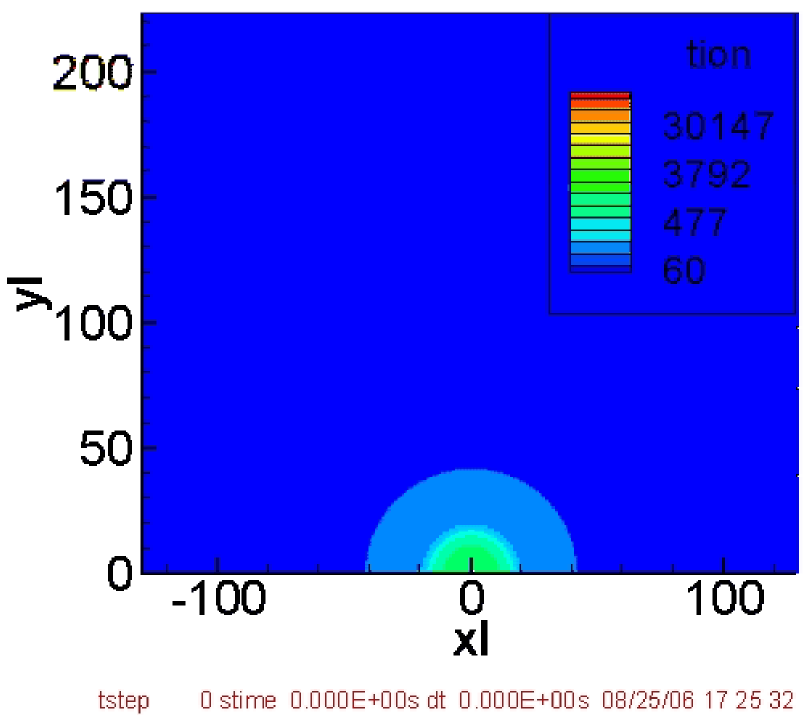
- A simple straight-line transport model is chosen for relativistic electrons, taking into account (approximately) the effects of multiple scattering and collective plasma oscillations.[3]

[1] P. B. Radha *et al.*, Phys. Plasmas 12, 056307 (2005).
[2] J. A. Delettrez *et al.*, Plasma Phys. Control. Fusion 47, B791 (2005).
[3] C. K. Li and R. D. Petrasso, Phys. Rev. E 70, 067401 (2004).

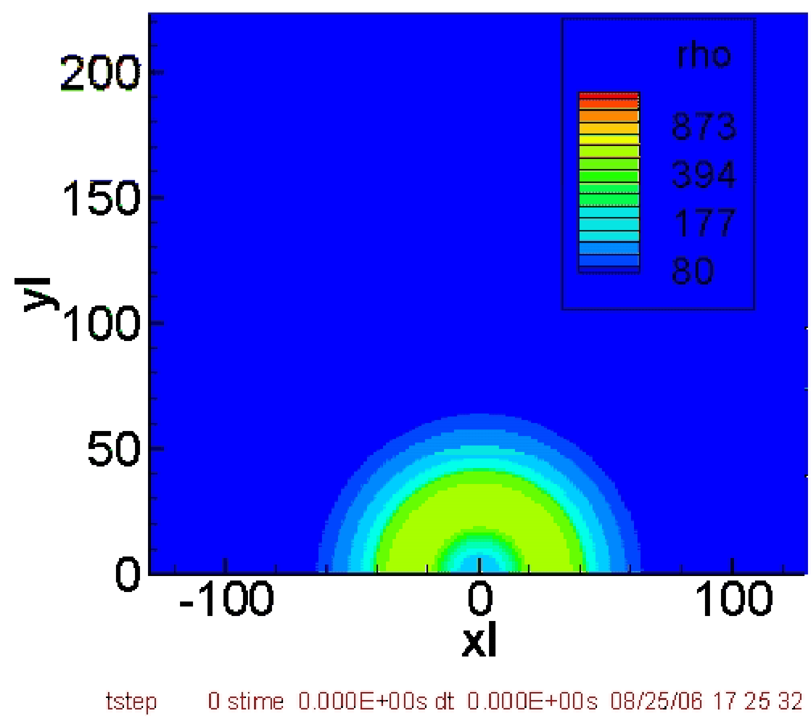
TC7618

Ignition is triggered by a 15-kJ, 2-MeV monoenergetic electron beam in the burn simulation

300-kJ fuel assembly
Ion temperature (keV)



300-kJ fuel assembly
Density (g/cm^3)



Electron-beam radius r_0 = 20 μm and duration τ = 20 ps.

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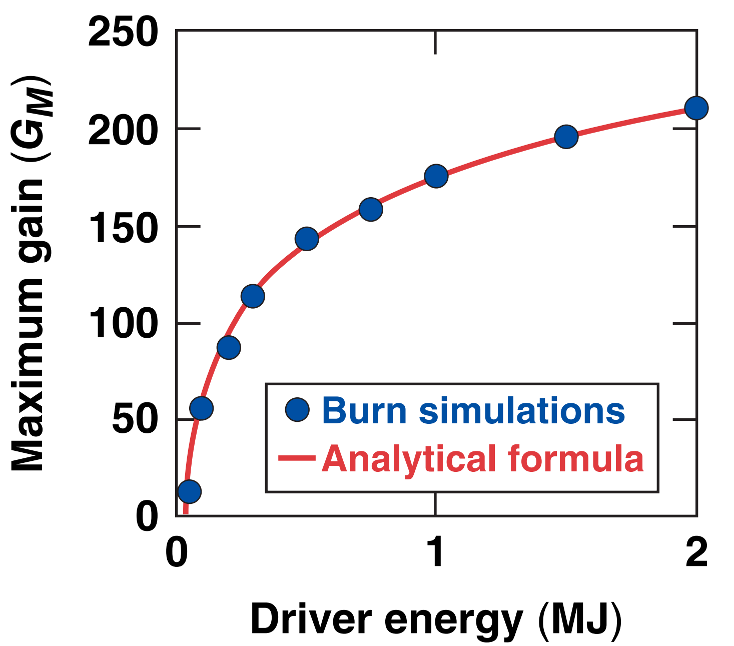
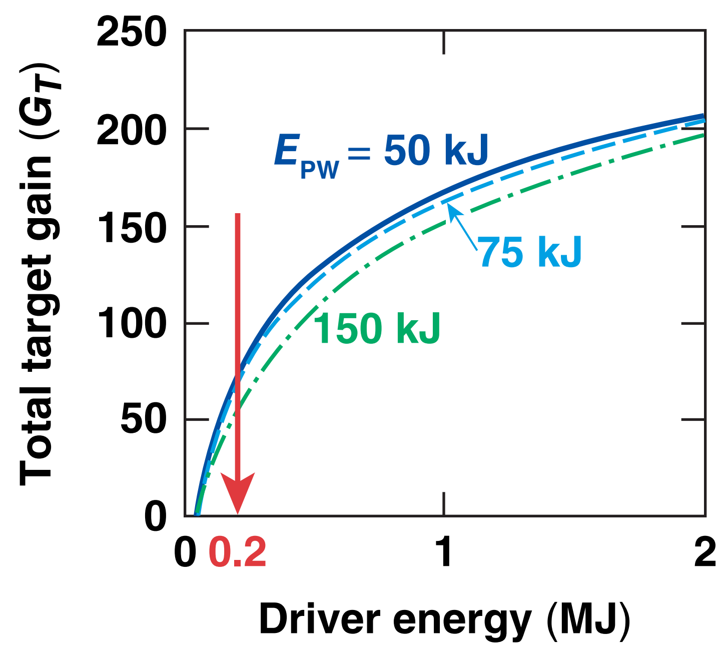
High gains are possible with small drivers with energy as low as 200 kJ

$$G_M = \frac{E_{\text{Fusion}}}{E_{\text{Driver}}} \approx \frac{743}{1 + 30 / E_{\text{Driver}}^{0.33}(\text{kJ})}$$



$$G_T = \frac{E_{\text{Fusion}}}{E_{\text{Driver}} + E_{\text{Petawatt}}}$$



TC7620

R. Betti, A. A. Solodov, J. A. Delettrez, and C. Zhou, Phys. Plasmas 13, 100703 (2006).

Using Maxwellian electrons and Gaussian laser pulses increases the energy required for ignition

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Ponderomotive temperature scaling:[1]

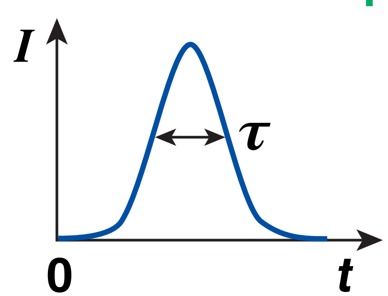
$$\langle E_{hot}\rangle = \left[\frac{I(\lambda/1.054\ \mu\text{m})^2}{10^{19}\ \text{W cm}^{-2}}\right]^{1/2}\ \text{MeV}$$

Electron range: $R = 0.6 \times \langle E_{hot}\rangle$ g/cm^2

- $\langle E_{hot}\rangle$ >> 1: Electron range greatly exceeds the optimal range for fast ignition,[2]

$$R_{opt} \sim 0.6 \div 1.2\ \text{g/cm}^2$$

Gaussian laser pulse



What is the minimum energy for ignition?

[1] S. C. Wilks *et al.*, Phys. Rev. Lett. 69, 1383 (1992).
[2] S. Atzeni, Phys. Plasmas 6, 3316 (1999).

TC7621

A minimum laser energy for ignition ≥100 kJ for λ_L = 1.05 μm

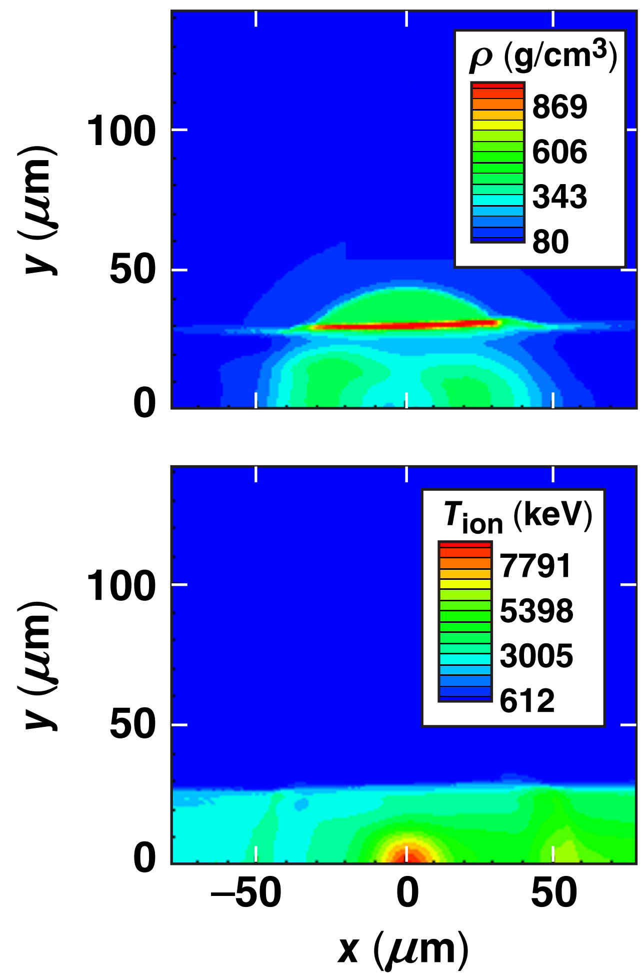
λ = 1.054 μm

η_{PW}	Minimum PW laser energy (kJ)	Electron-beam energy (kJ)	$\langle E_{hot} \rangle$ (MeV)	E-beam-fuel coupling efficiency
0.3	230	70	7.7	0.68
0.5	100	50	6.3	0.76

Ignition energy is minimized for $r_0 \simeq 25$ μm, $\tau \simeq 20$ ps.

E_{laser} = 230 kJ, η = 0.3,
r_0 = 25 μm, τ = 20 ps

300 kJ target



Frequency doubling reduces the electron mean energy, stopping length, and the minimum energy for ignition*

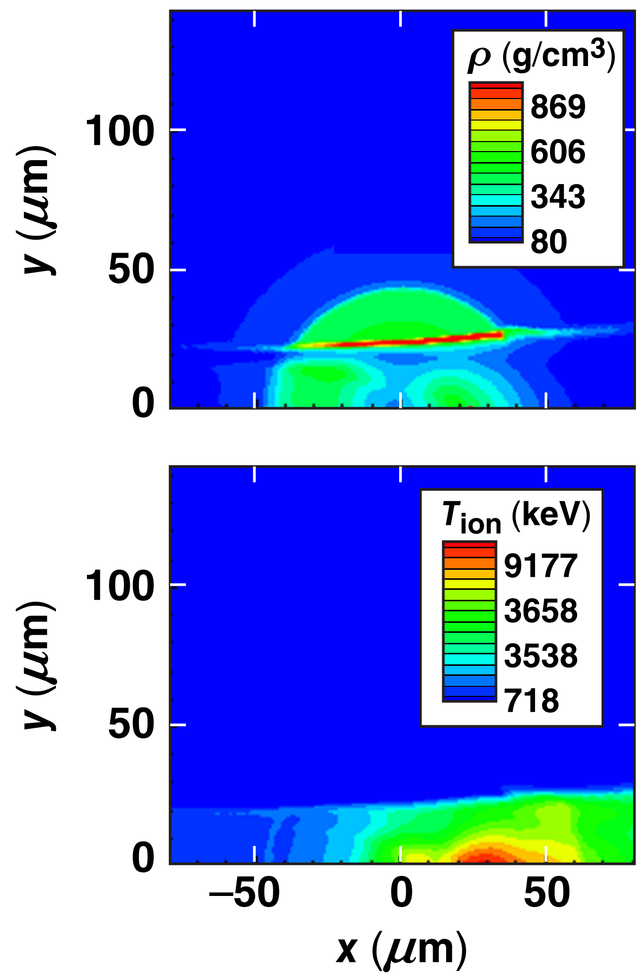
$\lambda = 0.527\ \mu m$

η_{PW}	Minimum PW laser energy (kJ)	Electron-beam energy (kJ)	$\langle E_{hot} \rangle$ (MeV)	E-beam-fuel coupling efficiency
0.3	110 (230)	33	3.7	0.93
0.5	55 (100)	28	3.2	0.99

Ignition energy is minimized for $r_0 \simeq 20\ \mu m$, $\tau \simeq 15$ ps.

$E_{laser} = 110$ kJ, $\eta = 0.3$,
$r_0 = 20\ \mu m$, $\tau = 15$ ps

300 kJ target



TC7623

*Also suggested in S. Atzeni and M. Tabak, Plasma Phys. Control. Fusion 47, B769 (2005).

Summary/Conclusions

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