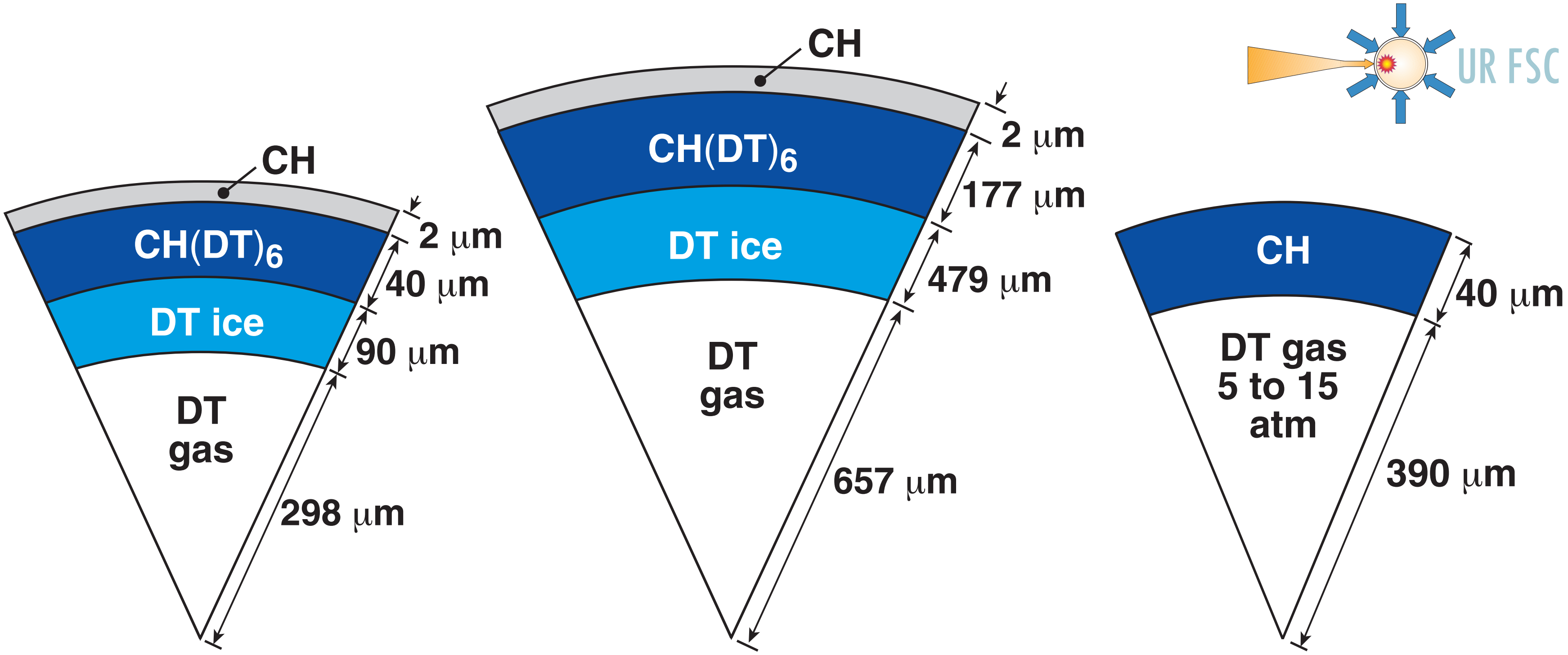
High-Density and High-ρR Fuel Assembly for Fast Ignition



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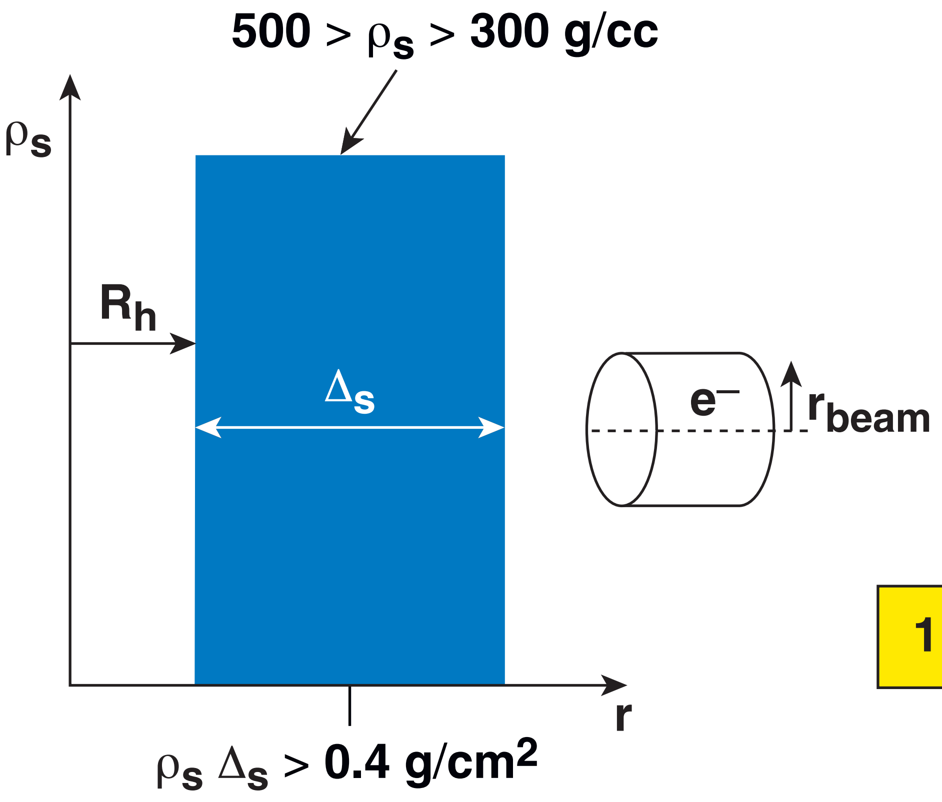
Summary

Significant progress has been made in the design of the fuel assembly for fast ignition using low-adiabat, low-velocity implosions

- A high-yield fuel assembly has been designed; it requires a 750-kJ driver to produce
  - $\rho R \approx 3$ g/cm^2
  - $300 < \rho < 500$ g/cc
  - hot-spot volume/total volume ~5% to 7%
  - estimated yield ~120 MJ (if ignited)
- A similar cryo target scaled down to 25 kJ yields $\rho > 300$ g/cc and $\rho R \approx 0.8$ g/cm^2.
- This method for assembling FI fuel will be first tested through 20-kJ plastic-shell implosions on OMEGA.

Ignition with fast ignition requires a fuel assembly with densities of 500 > ρ > 300 g/cc, ρR > 0.4 g/cm^2 and small hot-spot volume



$$E_{ig}\,(\text{kJ}) = 11\left[\frac{400}{\rho\,(\text{g/cc})}\right]^{1.85}$$

$$r_{beam}\,(\mu\text{m}) = 15\left[\frac{400}{\rho\,(\text{g/cc})}\right]^{0.95}$$

1 MeV e-stopping $\rho_s \Delta_s > 0.4$ g/cm^2

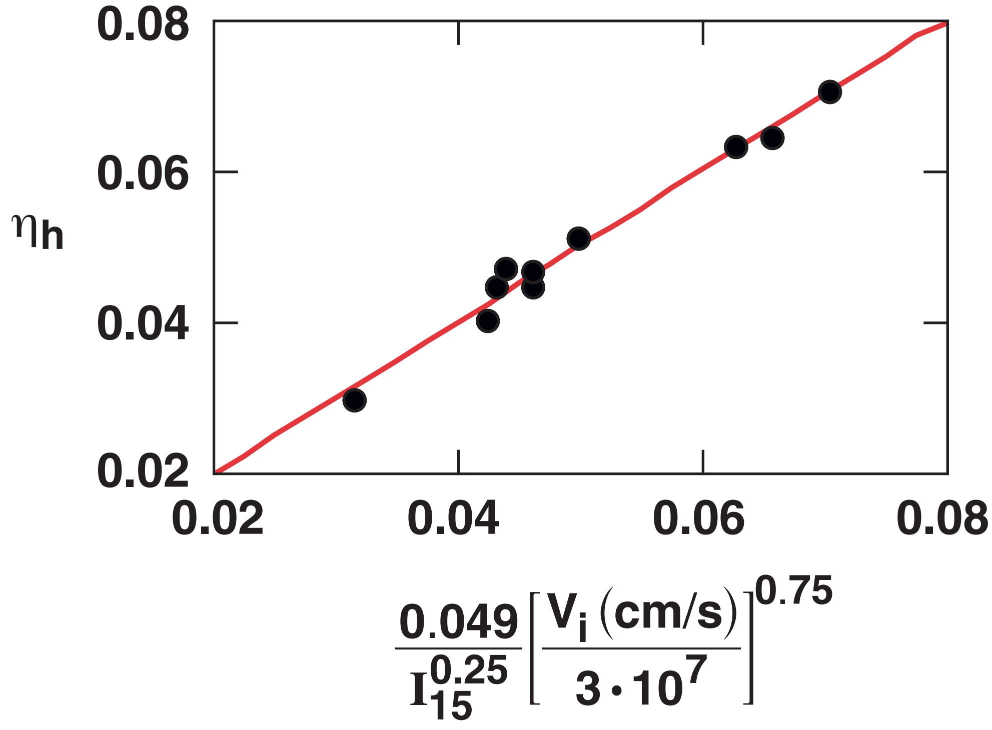
S. Atzeni, Phys. Plasmas 6, 3316 (1999).
C. K. Li and R. D. Petrasso, Phys. Rev. E. 70, 067401 (2004).

High yields with fast ignition require $\rho > 300$ g/cc, $\rho R \sim 3$ g/cm^2, small hot-spot volume, and gains > 100

$$\boxed{\text{Gain} = \frac{\eta_h}{V_i^2}\,\frac{\theta E_f}{m_{ion}}}$$

Fraction burned $\rightarrow \theta \approx \dfrac{1}{1 + 7/\rho R}$

Hydro-efficiency $\rightarrow \eta_h = \dfrac{E_{kinetic}}{E_{Laser}}$



$$\boxed{\text{Gain} = \frac{73}{I_{15}^{0.25}}\left(\frac{3 \cdot 10^7}{V_i}\right)^{1.25}\left(\frac{\theta}{0.2}\right)}$$

TC7069

Scaling laws are derived to design targets for integrated FI experiments; low α, low-velocity implosions of massive shells yield small hot spots and large areal densities

$$\frac{R_{\text{hot spot}}^{\text{stagnation}}}{\Delta_{\text{shell}}^{\text{stagnation}}} \approx 2.1\left(\frac{V_i\,(\text{cm/s})}{3\times10^{7}}\right)^{0.96}$$

$$(\rho R)_{\max} \approx \frac{1.3}{\alpha_{\text{if}}^{0.55}}\left[\frac{E_L\,(\text{kJ})}{100}\right]^{0.33} \text{g/cm}^2$$

$$\rho_{\max} \approx \frac{792}{\alpha_{\text{if}}} I_{15}^{0.13}\left[\frac{V_i\,(\text{cm/s})}{3\times10^{7}}\right] \text{g/cm}^3$$

TC7230

R. Betti and C. Zhou, Phys. Plasmas (in press).

High-gain fuel assemblies for fast ignition can be designed using the scaling formulas

UR LLE

→ Low adiabats enhance densities and areal densities: minimum practical adiabat $\alpha = 0.7$ to 0.8

→ $\rho R(\alpha = 0.7) \approx 3 \Rightarrow E_{Laser} \approx 750$ kJ

→ $\rho_{max}(\alpha = 0.7) \approx 600$ g/cc $\Rightarrow V_i(\text{cm/s}) \approx 1.7 \bullet 10^7$ cm/s

→ $V_i \approx 1.7 \bullet 10^7$ cm/s $\Rightarrow R_h/\Delta_s \sim 1$

High-gain FI target: $E_L = 750$ kJ, $\alpha = 0.7$, $V_i \approx 1.7 \bullet 10^7$ cm/s

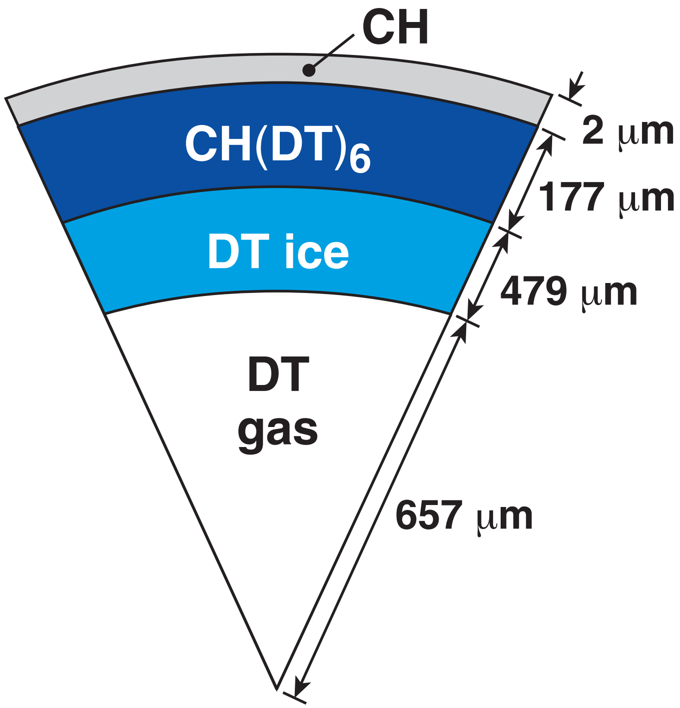
Estimated yield ~ 120 MJ

In-flight aspect ratio (IFAR) = 18

TC7072a

R. Betti and C. Zhou, Phys. Plasmas (in press).

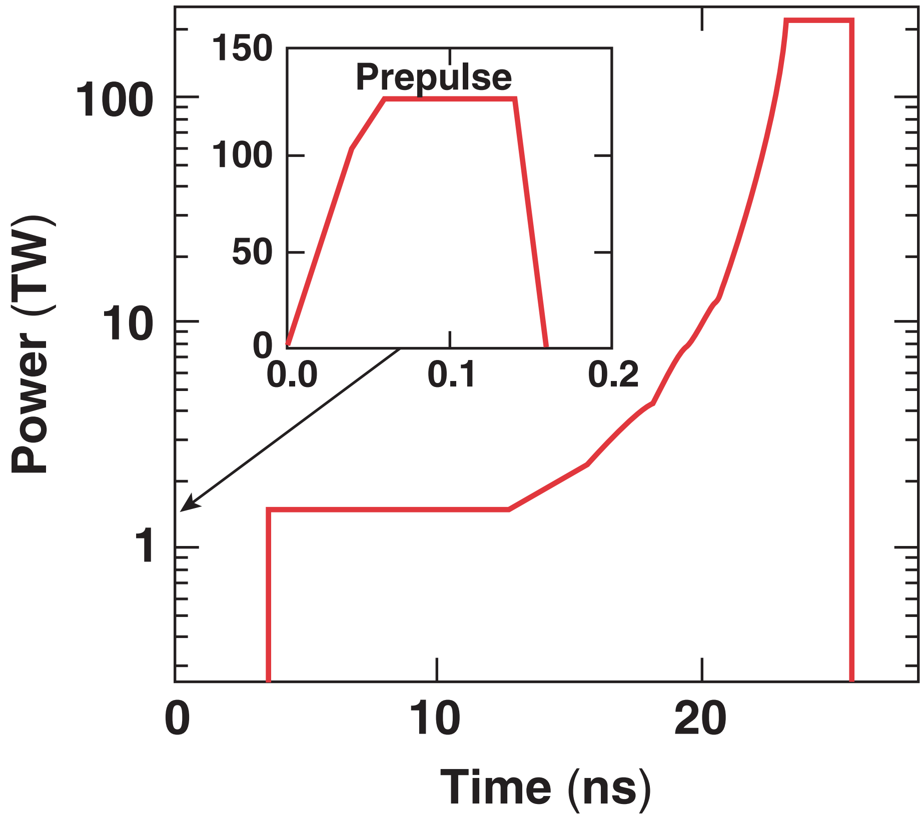
A high-yield target has been designed for a 750-kJ laser driver



Energy	Implosion velocity	α	IFAR
750 kJ	$1.7 \cdot 10^7$ cm/s	0.7	18

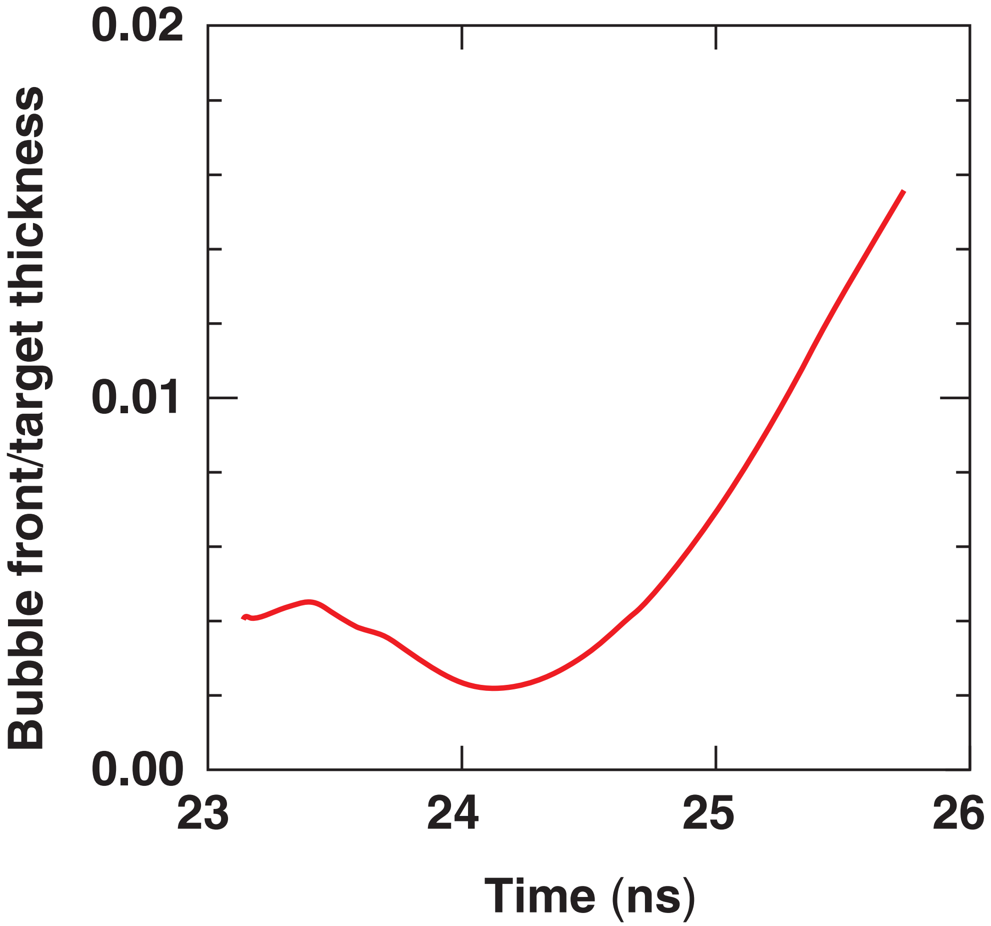
Maximum averaged density	Peak Density	Maximum ρR
550 g/cc	670 g/cc	3 g/cm^2

The 750-kJ capsule is driven by a relaxation laser pulse with a 22-ns main pulse and a contrast ratio of 150



Can NIF assemble high-gain FI targets?
Indirect-drive pulse is 18 ns with a contrast ratio of ~100

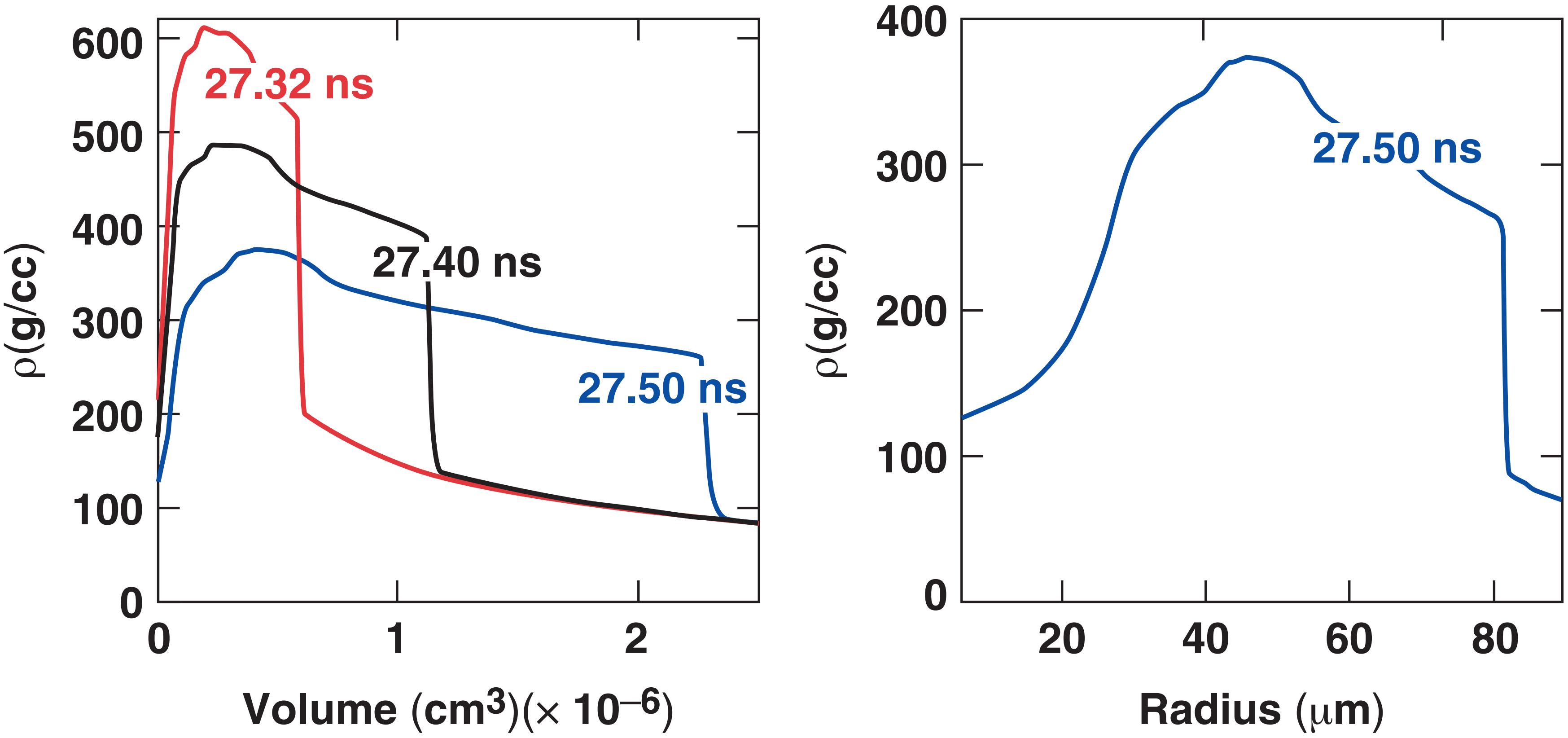
The slow implosion velocity leads to negligible Rayleigh–Taylor growth during the laser flat top



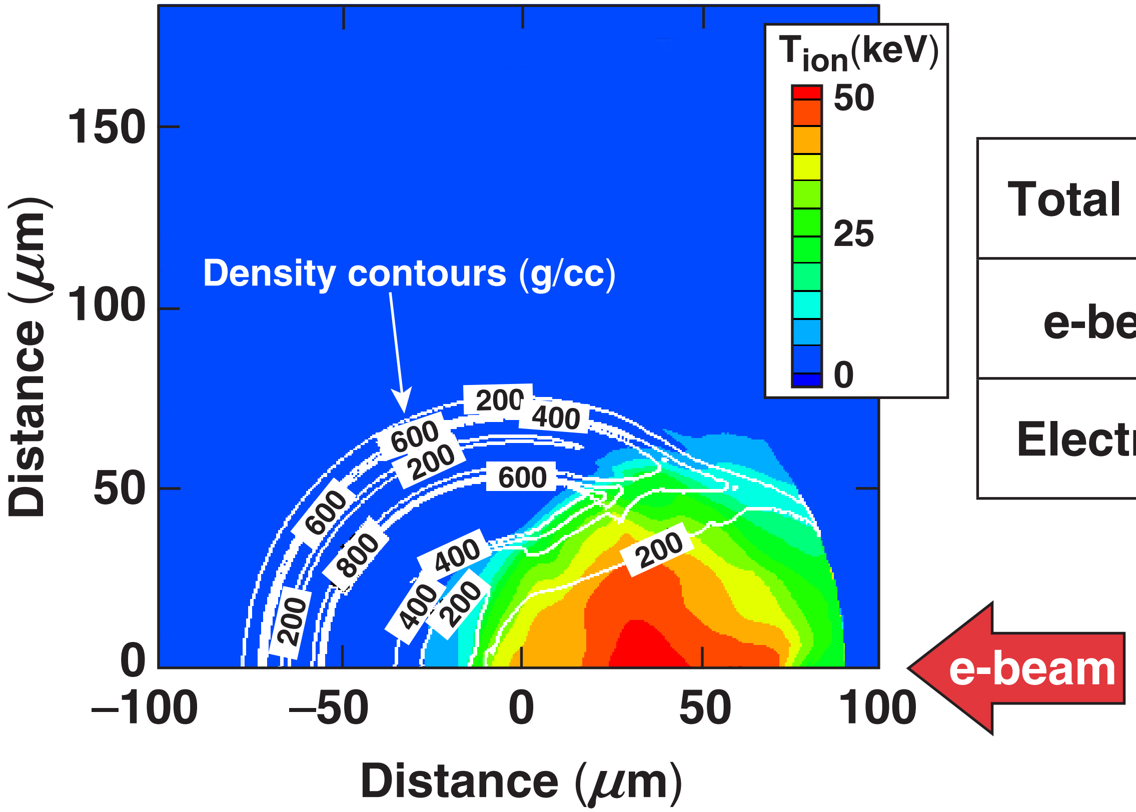
Results from RT postprocessor based on Haan–Goncharov models and NIF laser nonuniformities with 1-THz SSD.

V. N. Goncharov *et al*., Phys. Plasmas 7, 2062 (2000).
S. W. Haam, Phys. Rev. A 39, 5812 (1989).

The 750-kJ capsule yields a hot-spot volume < 8% of the compressed volume and a quasi-isochoric density profile



2-D hydro-simulations of ignition and burn of the 750-kJ target show energy yields >100 MJ



Total beam energy (kJ)	12–20
e-beam radius (μm)	20
Electron energy (MeV)	2–3

Energy yield ≈ 116 MJ

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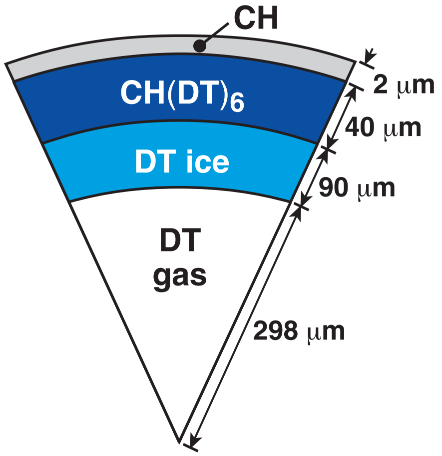
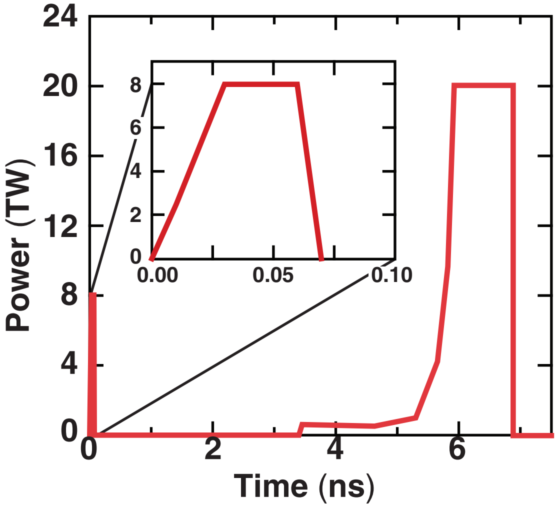
*J. A. Delettrez, this conference

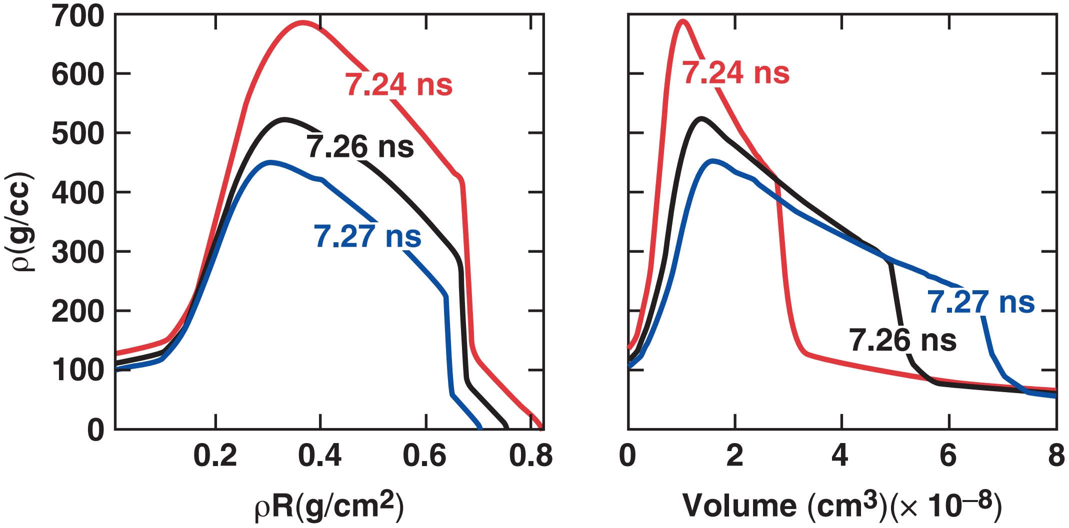
Similar targets scaled down to 25 kJ can be assembled on OMEGA yielding high $\rho > 300$ g/cc and $\rho R \approx 0.8$ g/cm^2



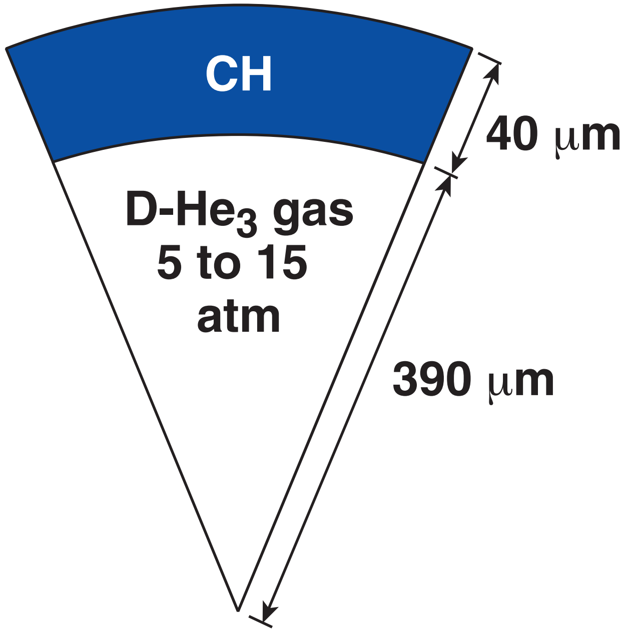
25-kJ OMEGA cryo FI target

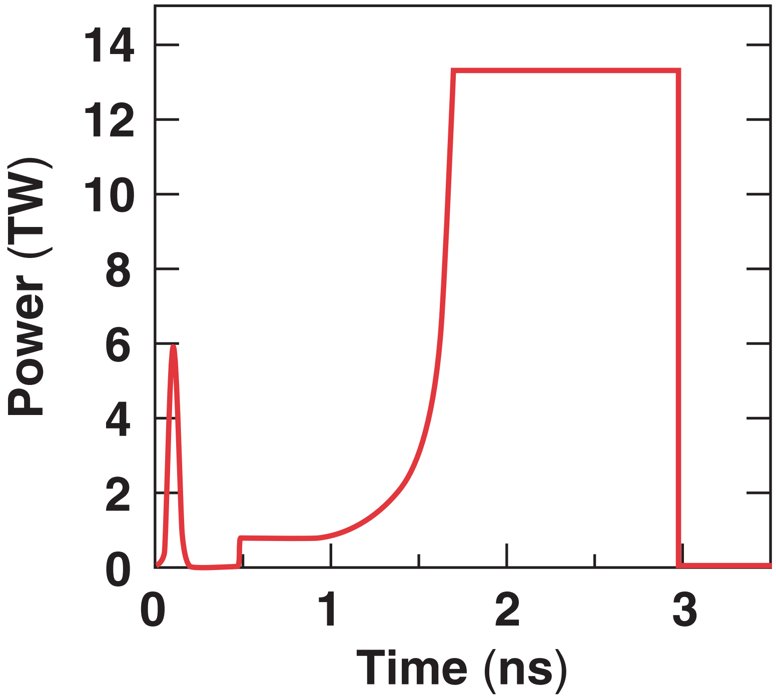
Energy	$(\rho R)_{max}$	ρ_{max}
25 kJ	0.8 g/cm^2	700 g/cc





This method for assemblying FI fuel will be first tested on OMEGA with surrogate plastic-shell implosions





Energy	α	Implosion velocity	Maximum ρR (5–15 atm)	Maximum ρ (5–15 atm)	Proton yield (5–15 atm)
20 kJ	1.2	$2.1 \cdot 10^7$ cm/s	0.5–0.36 g/cm^2	276–190 g/cc	$1.2–2.3 \cdot 10^8$

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