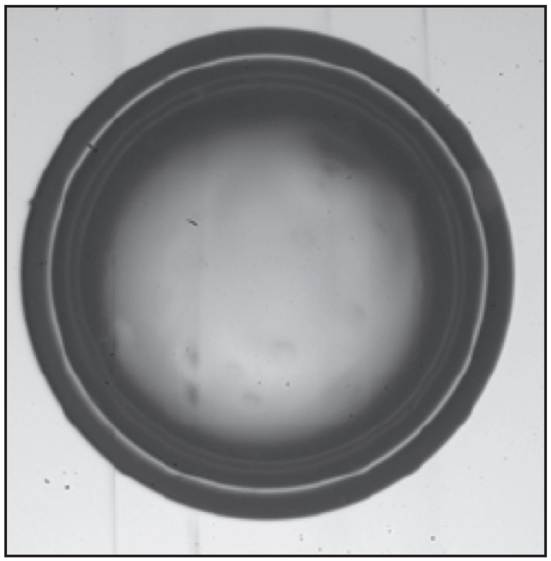
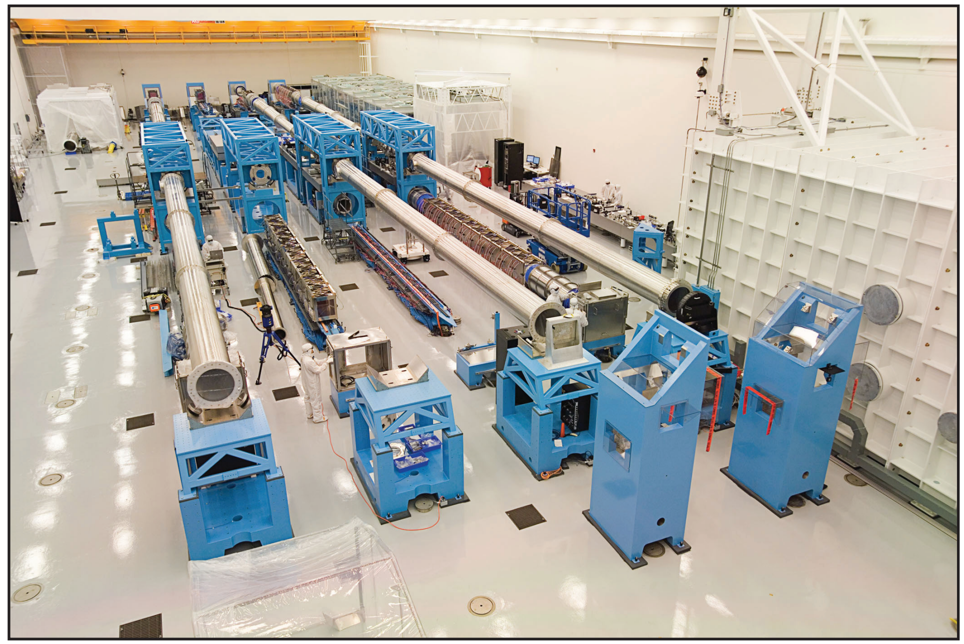
ICF and IFE Research at the Laboratory for Laser Energetics



β-layered
DT Cryogenic Target



OMEGA EP

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Fusion Power Associates
Washington, D. C.
27 September 2006

Summary

The Laboratory for Laser Energetics is validating concepts for ICF ignition

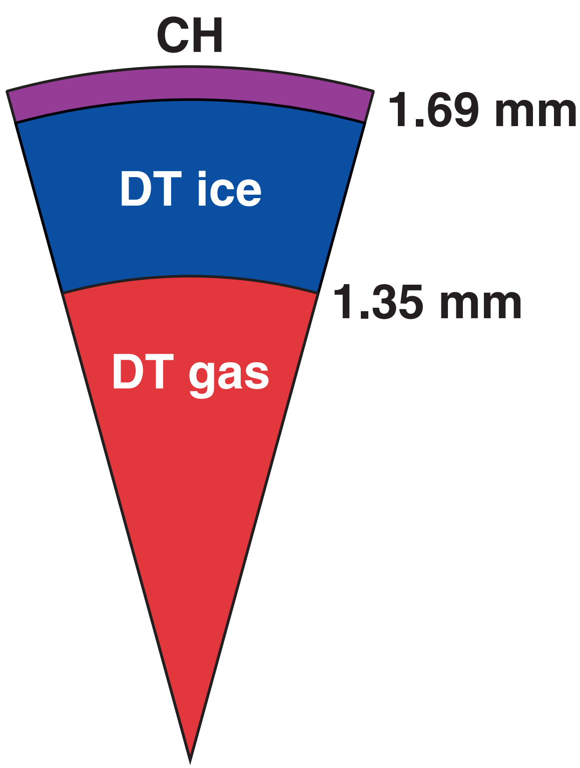
UR LLE

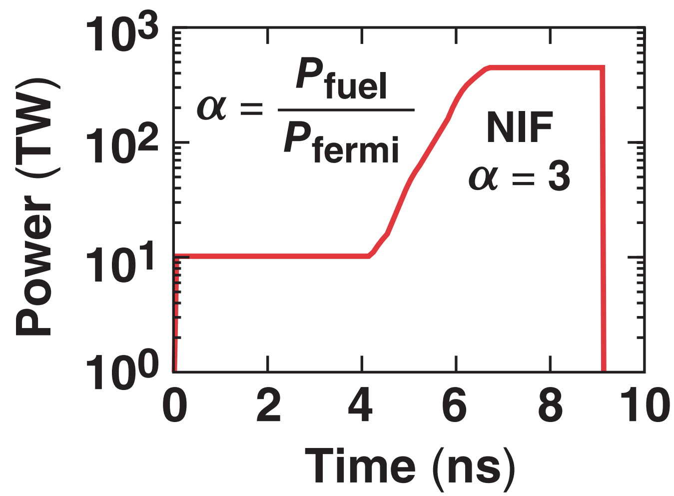
- The baseline direct-drive ignition target for the NIF is a thick cryogenic DT shell enclosed by a thin plastic shell.
- DT ice layer roughness <1-μm rms are routinely achieved.
- Ignition-scaled cryogenic D_2 and DT implosions are underway.
- Polar direct-drive (PDD) will allow direct-drive ignition experiments while NIF is configured for indirect drive.
- A new high-energy petawatt laser system—OMEGA EP—is under construction at LLE (completion April 2008).
- Integrated fast-ignition experiments will begin in 2009.
- National Ignition Campaign (NIC) success is a prerequisite for Inertial Fusion Energy (IFE).

ICF physics validation is required for IFE.

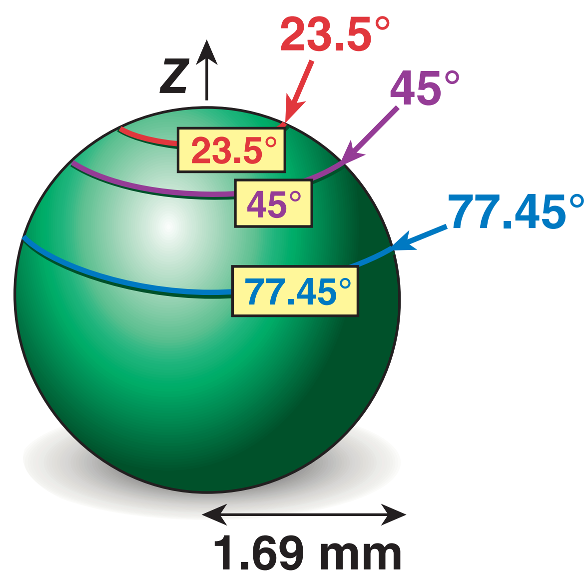
Symmetric Drive

The NIF symmetric direct-drive point design is a thick DT-ice layer enclosed by a thin CH shell





Symmetric Drive



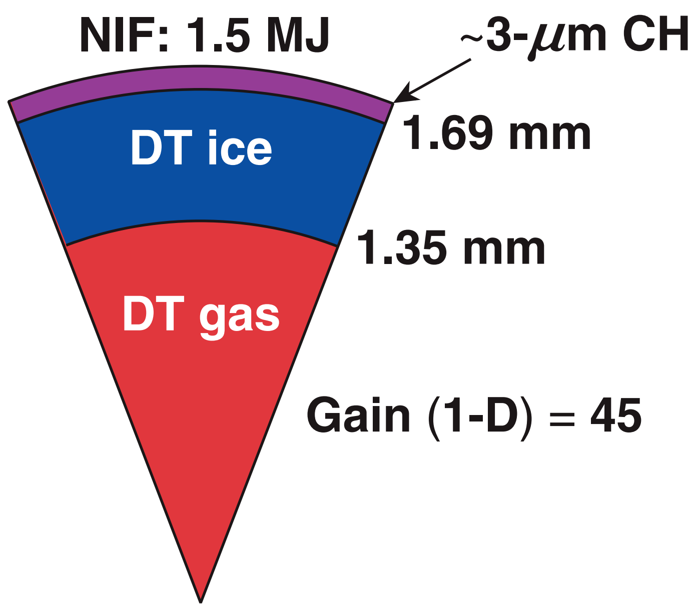
Energy: 1.5 MJ

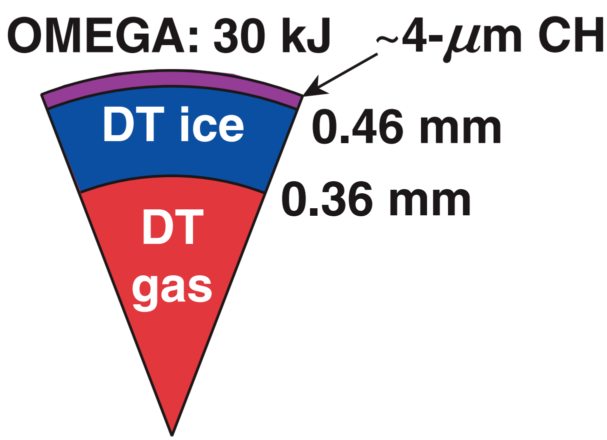
Absorption fraction: 63%

Gain $\left(\dfrac{\text{fusion energy out}}{\text{laser energy in}}\right)$: 45

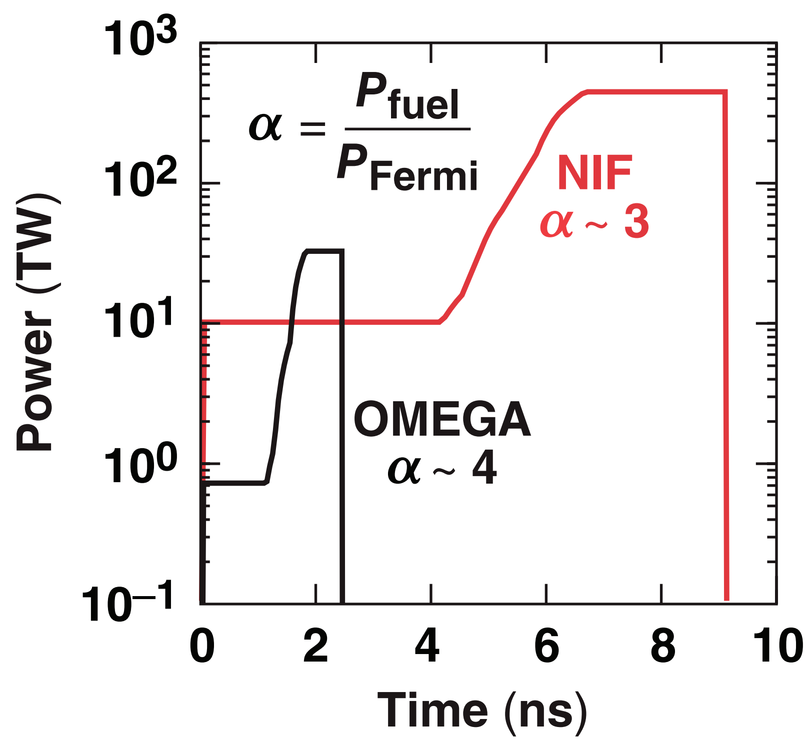
TC5576e

OMEGA cryogenic targets are energy scaled from the NIF symmetric direct-drive point design





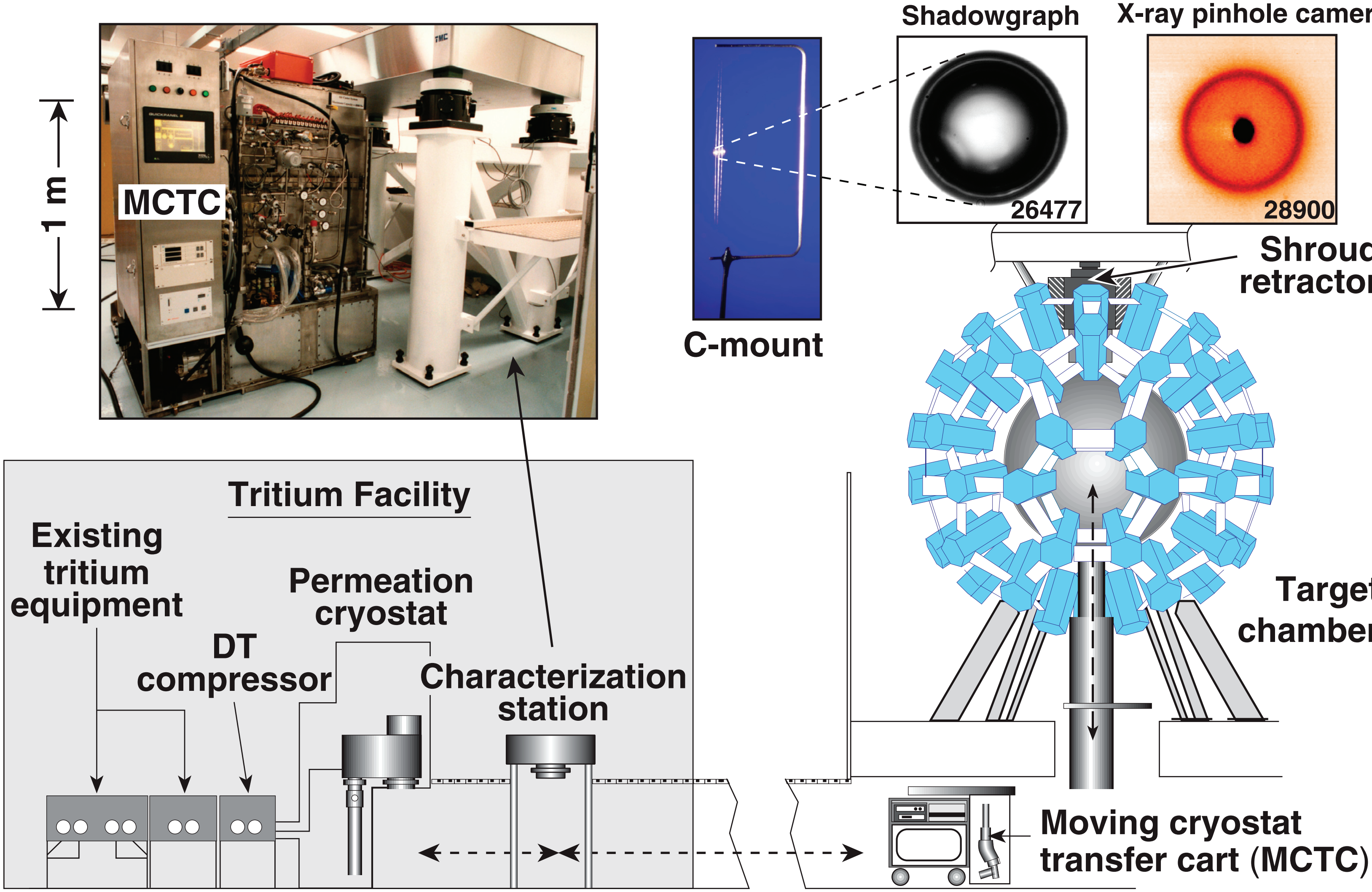
Energy ~ radius^3
Power ~ radius^2
Time ~ radius



E11251m

OMEGA Cryogenic Capsules

A reliable cryogenic fuel system is required for IFE



- **Target positioning accuracy is challenging with cryogenic targets.**

E12062f

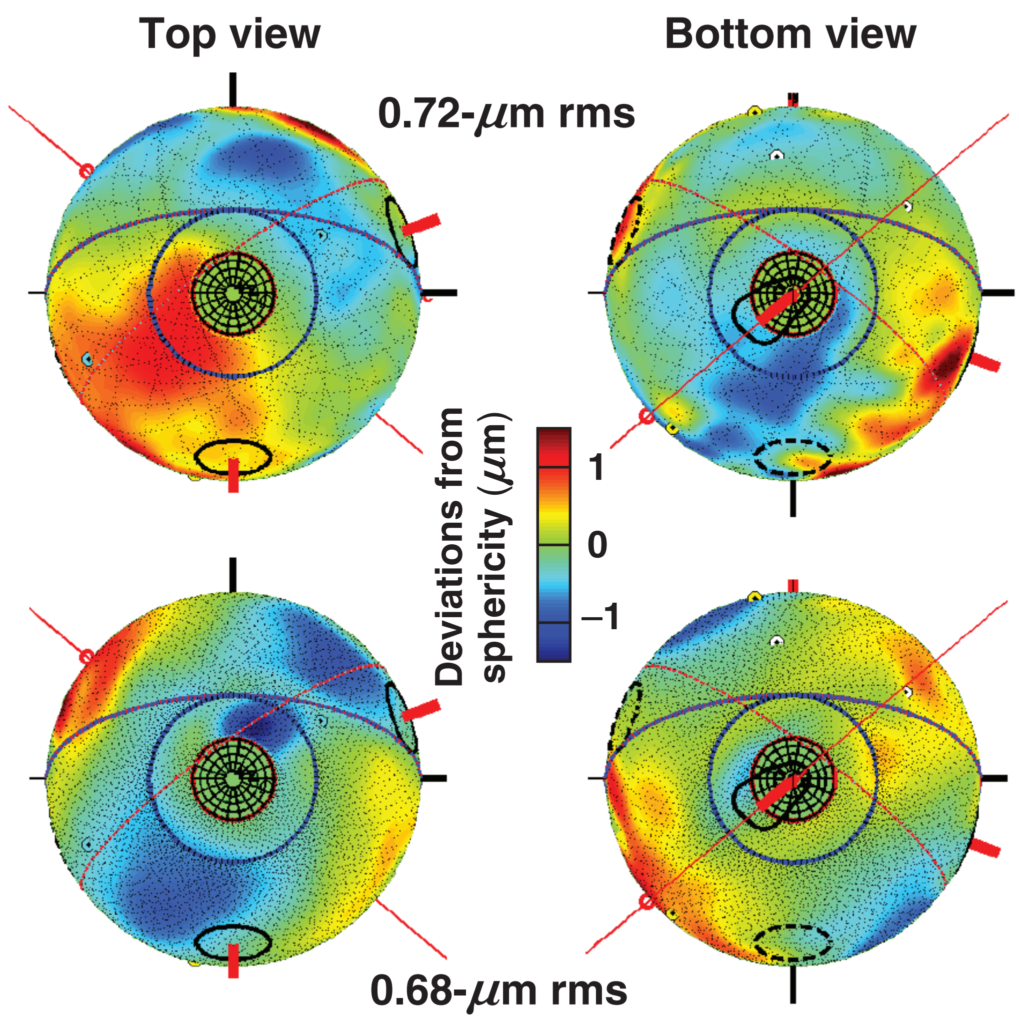
β-layered 50:50 DT cryogenic targets have been imploded on OMEGA

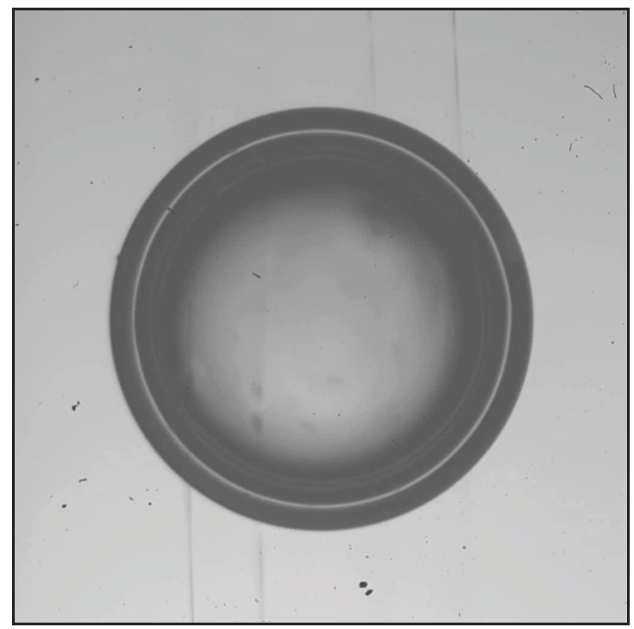
UR LLE

- β-layered 50:50 DT cryogenic targets have ice roughness nonuniformity <1-μm rms.
- Progress in IR layering of D_2 cryogenic targets have led to ice roughness nonuniformity <2-μm rms.
- Diagnostics show that the ice uniformity is maintained at shot time.
- DT and D_2 implosions allow different diagnostics to interrogate target performance and improve hydrodynamic simulations.
- Peak areal densities are approaching 150 mg/cm^2.

Cryogenic target implosions on OMEGA will validate direct-drive target physics and numerical simulations.

We have produced four DT (45:55) ice layers with an ice roughness less than 1-μm rms for all modes, in three separate capsules



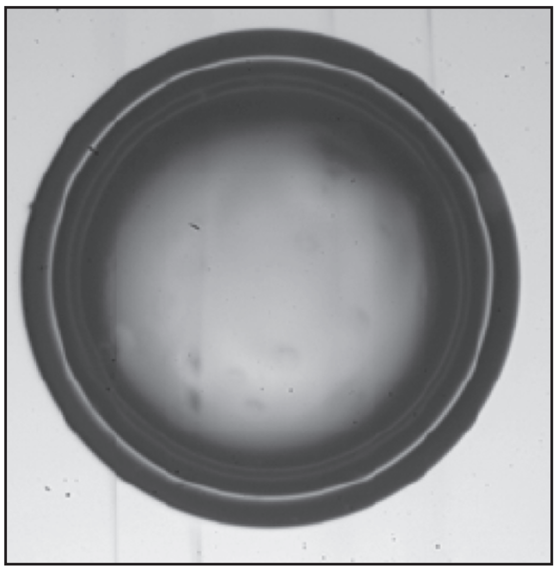


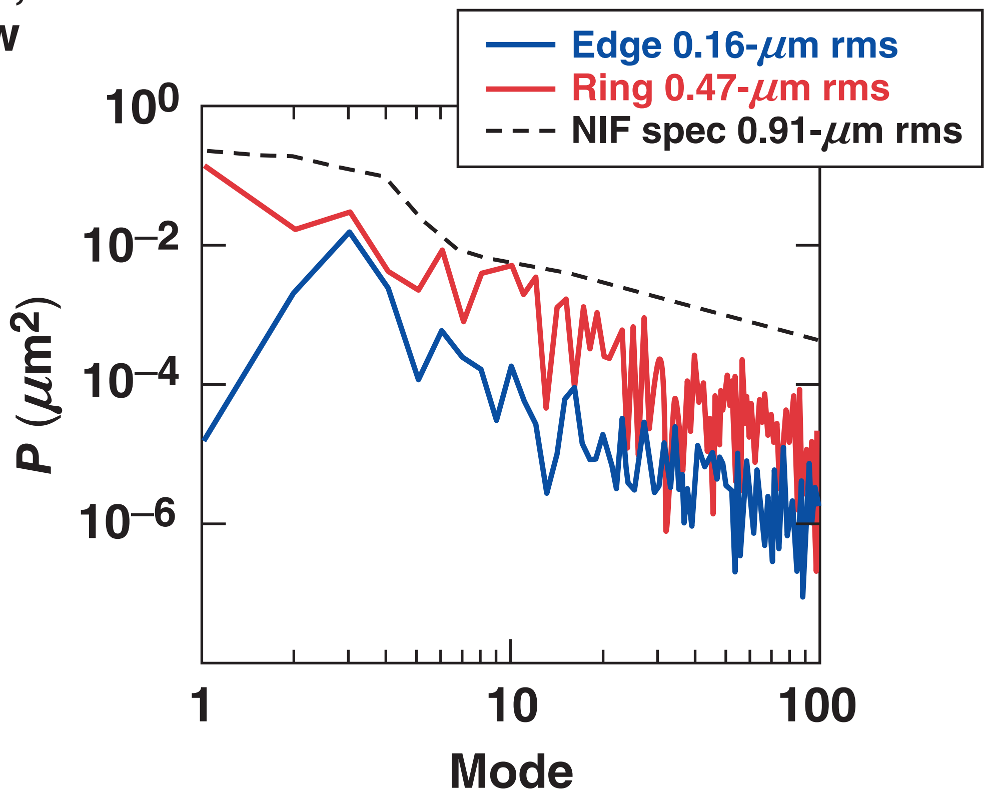
T2270a

The cryogenic DT layer roughness exceed the NIF direct-drive ignition specification

UR LLE

Formed from a single crystal; 0.47-μm rms in a single view





T2257b

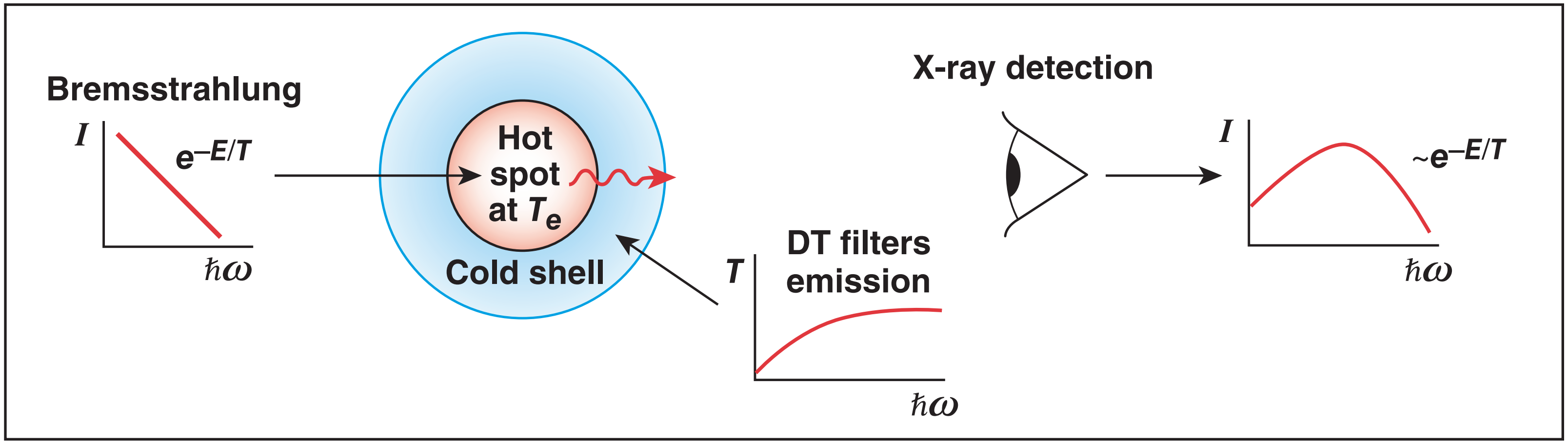
Both x-ray and neutron spectroscopy can be used to measure the ICF target core conditions[1]

- The self-emission spectrum at peak compression is exponential given by the electron temperature filtered by the areal density of the compressed shell.
- The emergent x-ray spectrum diagnoses the inner hot-spot electron temperature kT_e and shell areal density ρR_{shell}:

$$e^{-\mu\,\rho R_{shell}}\,e^{-E/kT_{hot}}$$

$$\mu(E,\rho,T) = \frac{0.44\,\rho_{shell}}{(E/keV)^3\,(kT_{shell}/keV)^{1/2}}$$

where $\mu(E)$ is the mass absorption coefficient.



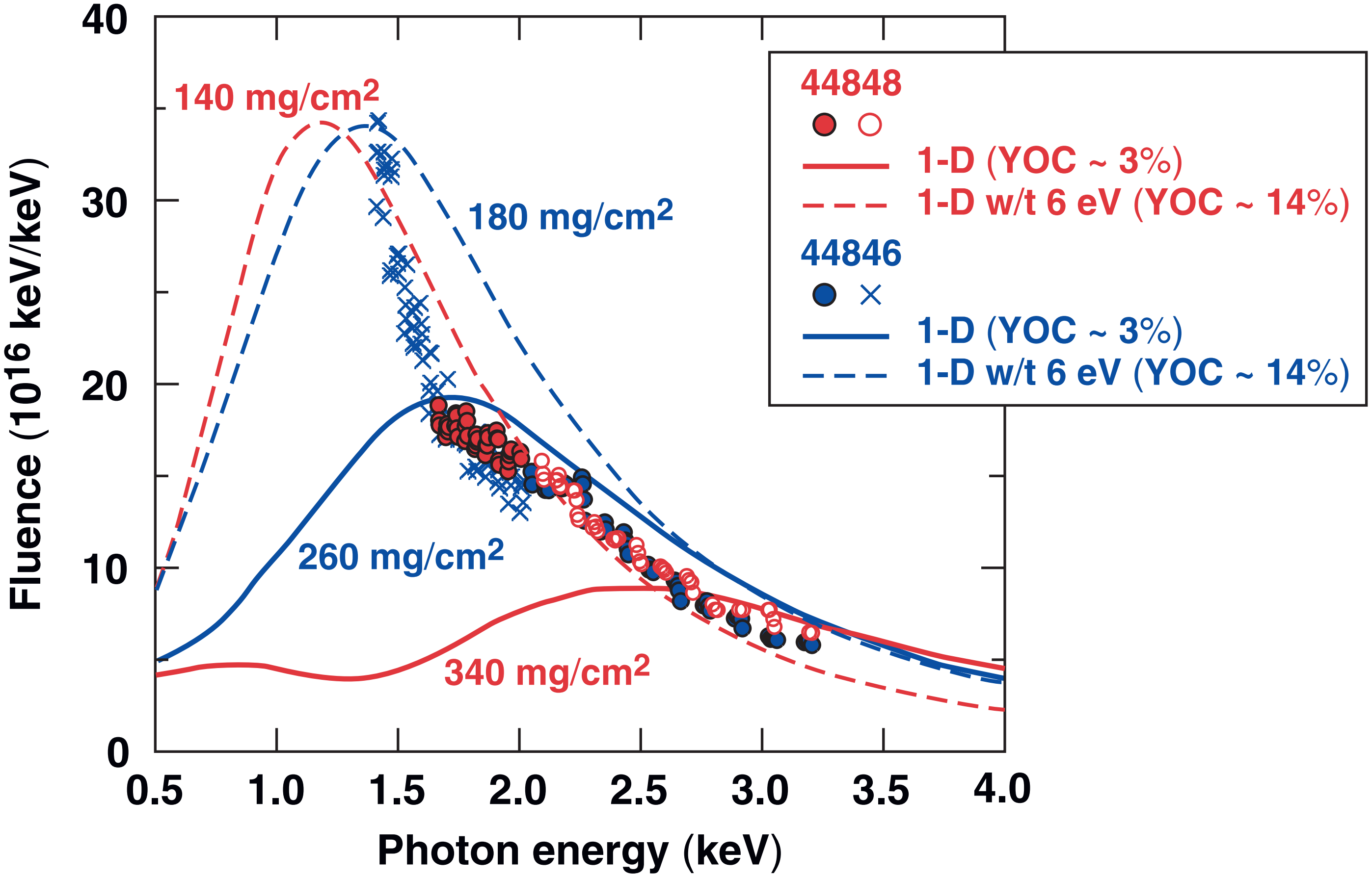
I1681

[1]F. J. Marshall *et al.*, Phys. Rev. E. 49, 4381 (1994).

X-ray spectra from DT cryo shots are compared to 1-D simulations to infer the areal density

UR LLE

- There is evidence that the compressed fuel is being preheated during the laser pulse.

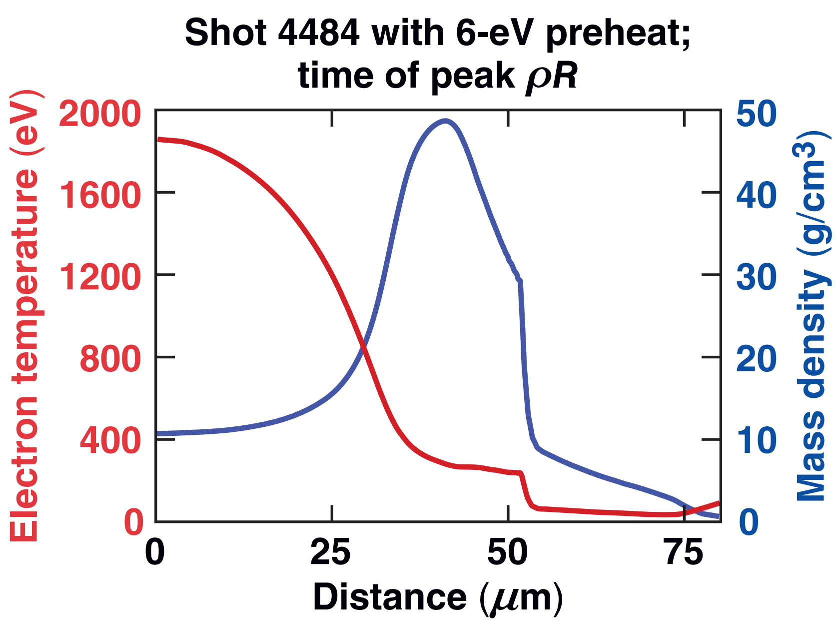


The estimated areal density is 140 mg/cm^2.

I1682

The Lawson criterion is estimated from the areal density and disassembly time

- The disassembly time is ~100 ps.
- The density is given by the areal density divided by the calculated shell thickness at peak compression.



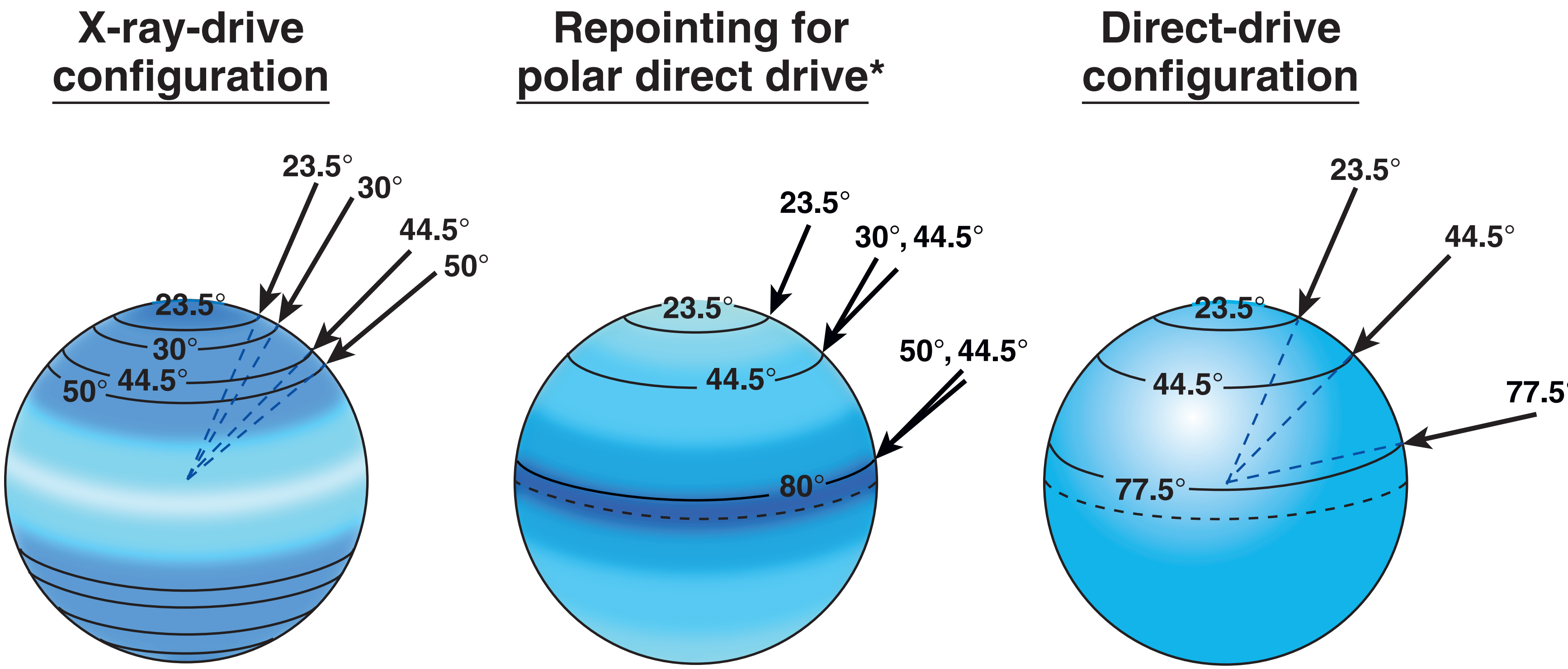
Fuel thickness from x-ray data and simulations: ΔR <50 μm

Mass density ρ = 25 to 50 g/cm^3

- The Lawson criterion is 6 ~12 $\times$ 10^{20} s/m^3.
- The $n_e \tau T$ is 3 ~20 $\times$ 10^{20} s keV/m^3 depending on whether the hot spot or shell temperature is used.

I1683

Polar direct drive (PDD) can achieve ignition while the NIF is in the x-ray-drive configuration



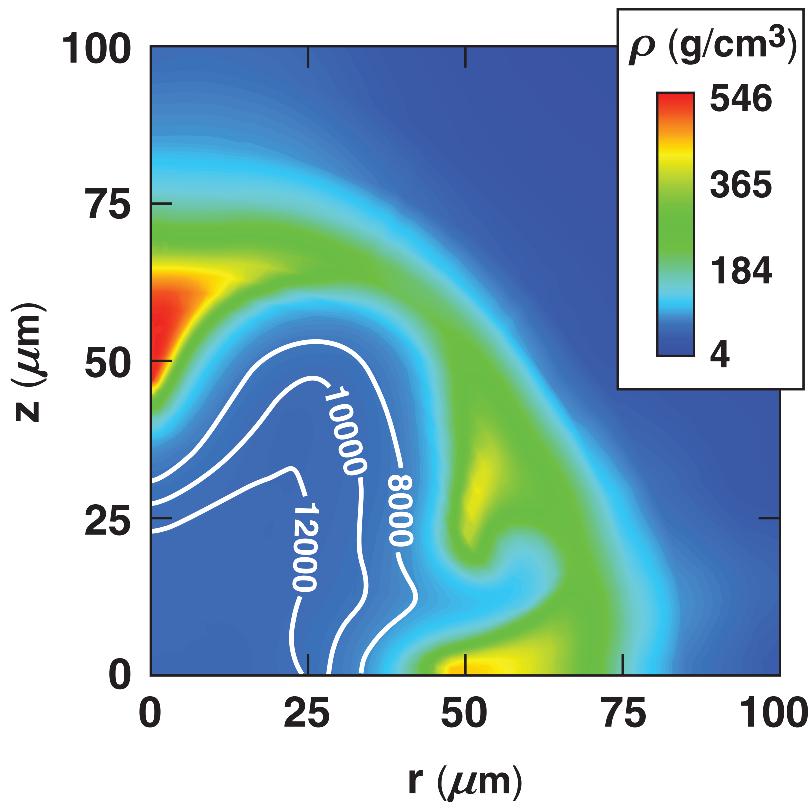
*Pointing for standard PDD

The latest NIF-scale PDD simulations ignite and achieve significant gain

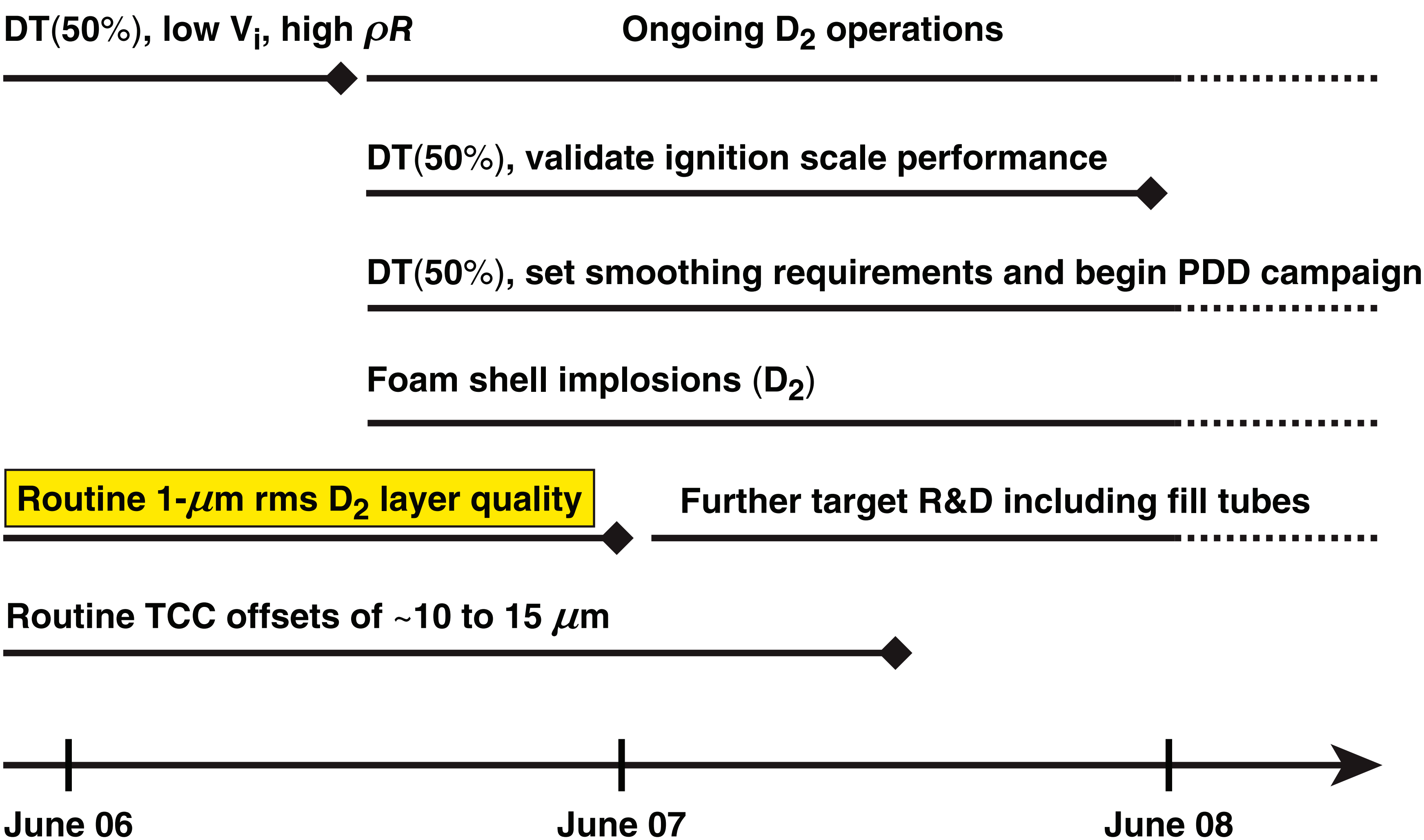
Cryogenic DT wetted CH foam

Simulation type	Incident energy	Absorbed energy	Gain
LILAC (1-D)	1.0 MJ	0.87 MJ	33
DRACO (2-D) PDD	1.3 MJ	1.0 MJ	20

Near peak compression, 8.12 ns



Direct-drive-ignition scaled performance will be validated over the next two years



E14603b

Nuclear diagnostics are being developed for the NIF on high-yield OMEGA experiments

UR LLE

- In 2005, the suite of the NIF nuclear diagnostics was defined
  - ✓ PROTEX: primary DT neutron yield
  - ✓ neutron time of flight (nTOF): D_2, DT yield, T_i, ρR
  - ✓ neutron activation diagnostic (NAD): DT yield, ρR
  - bang time/reaction history diagnostic
  - magnetic recoil spectrometer: ρR, DT yield, T_i
  - neutron imaging system

A multilab effort to specify system design requirements (SDR), and develop and integrate diagnostics on the NIF is in progress.

The neutron activation diagnostic (NAD) will measure primary and tertiary neutron yields on OMEGA and the NIF

- NAD will consist of copper and carbon activation.
- Copper activation* will measure the primary DT neutron yield.

$^{63}Cu\ (n,2n)\ ^{62}Cu$	$E_n > 10.9$ MeV
$^{62}Cu \rightarrow {}^{62}Ni + e^+$	$(T_{1/2} = 9.8$ min$)$
$e^+ + e^- \rightarrow 2\gamma$	(0.511 MeV)

- Carbon activation** will measure the tertiary neutron yield.

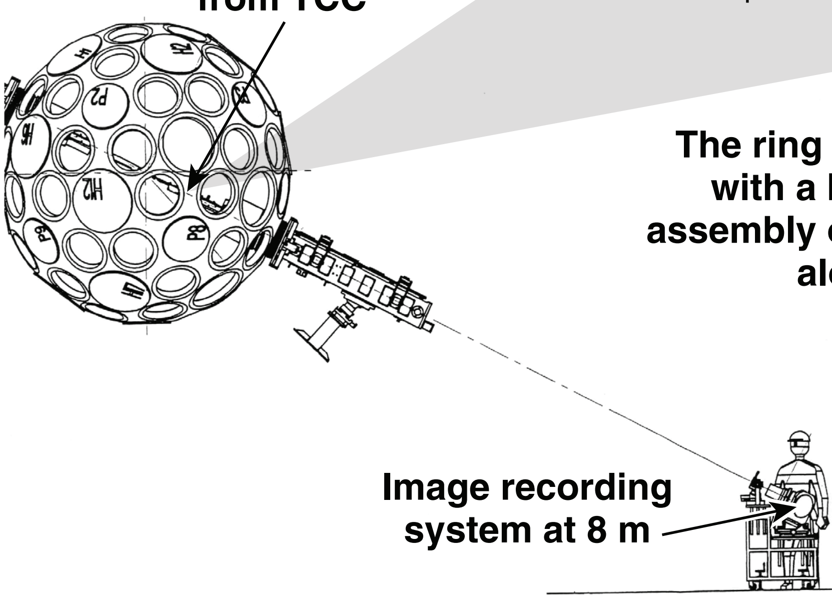
$^{12}C\ (n,\ 2n)\ ^{11}Cu$	$E_n > 22$ MeV
$^{11}C \rightarrow {}^{11}B + e^+$	$(T_{1/2} = 20.39$ min$)$
$e^+ + e^- \rightarrow 2\gamma$	(0.511 MeV)

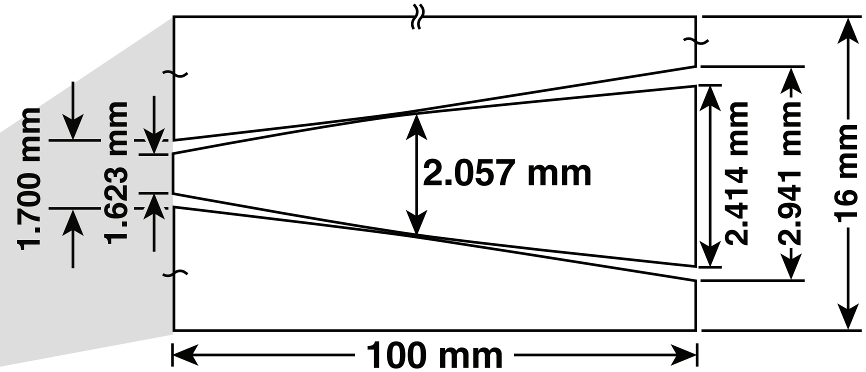
- Cu and C activations will use very similar counting systems and the same retraction system.

*R. A. Lerche *et al*., LLNL 1976 Annual Report
**V. Yu. Glebov *et al*., RSI 74, 1717 (2003).

E14485a

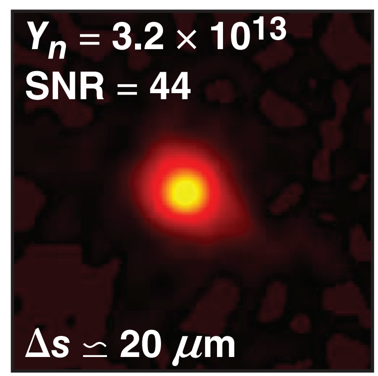
CEA developed penumbral- and ring-aperture neutron imaging on OMEGA





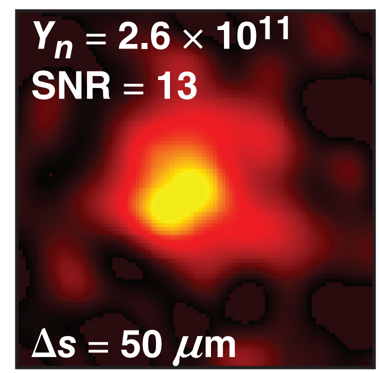
The ring aperture combines a penumbral aperture with a biconical plug to produce a continuous assembly of 8-mm-diam neutron pinholes distributed along a ring and aimed at the target.

DT(15)CH[15]



300 μm

D_2 cryogenic target



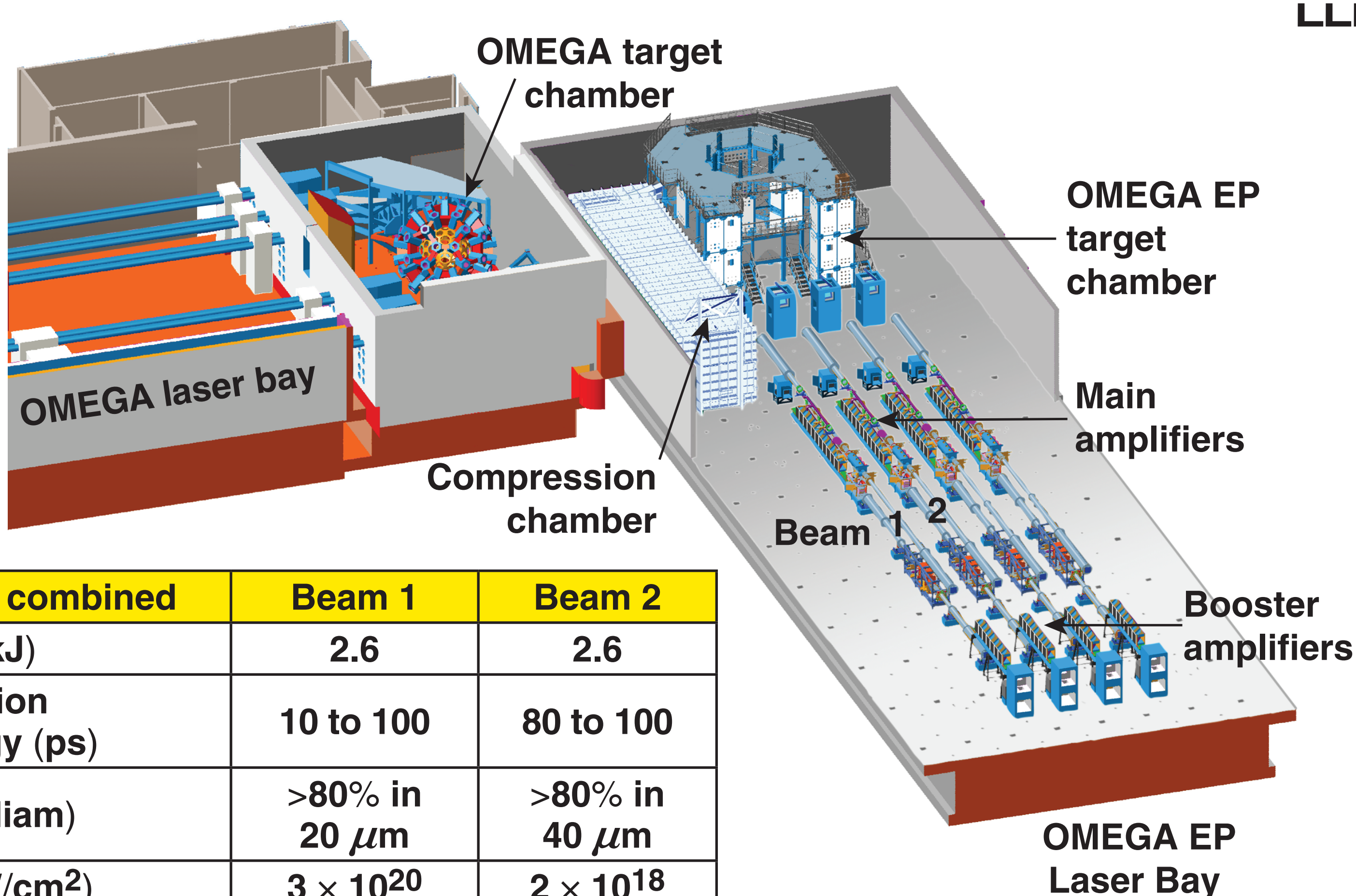
300 μm

E14497a

L. Disdier *et al.*, RSI 75, 2134 (2004).

OMEGA EP

The OMEGA EP laser system will be used to backlight cryogenic implosions and study fast ignition



Short pulse combined	Beam 1	Beam 2
IR energy (kJ)	2.6	2.6
Pulse duration at full energy (ps)	10 to 100	80 to 100
Focusing (diam)	>80% in 20 μm	>80% in 40 μm
Intensity (W/cm^2)	3×10^{20}	2×10^{18}

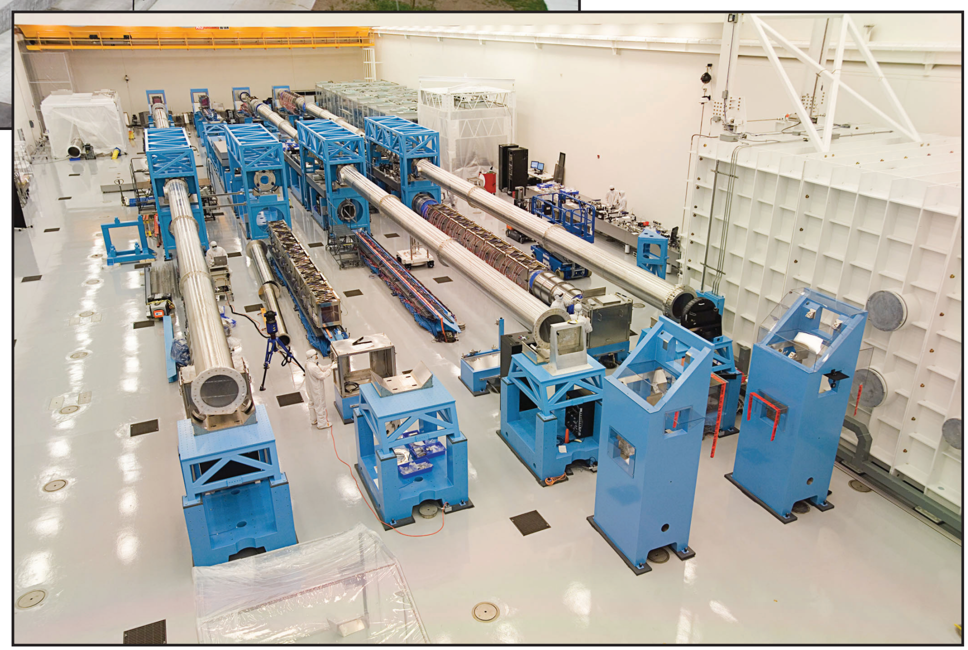
OMEGA EP will be completed in FY08.

- Each beam duration can be as short as 1 ps at reduced energy (grating damage and *B*-integral)
- Beam 2 can produce 2.6 kJ in 10 ps when propagating on a separate path

G6957i

OMEGA EP is progressing on schedule

OMEGA EP Building
(completed in February 2005)

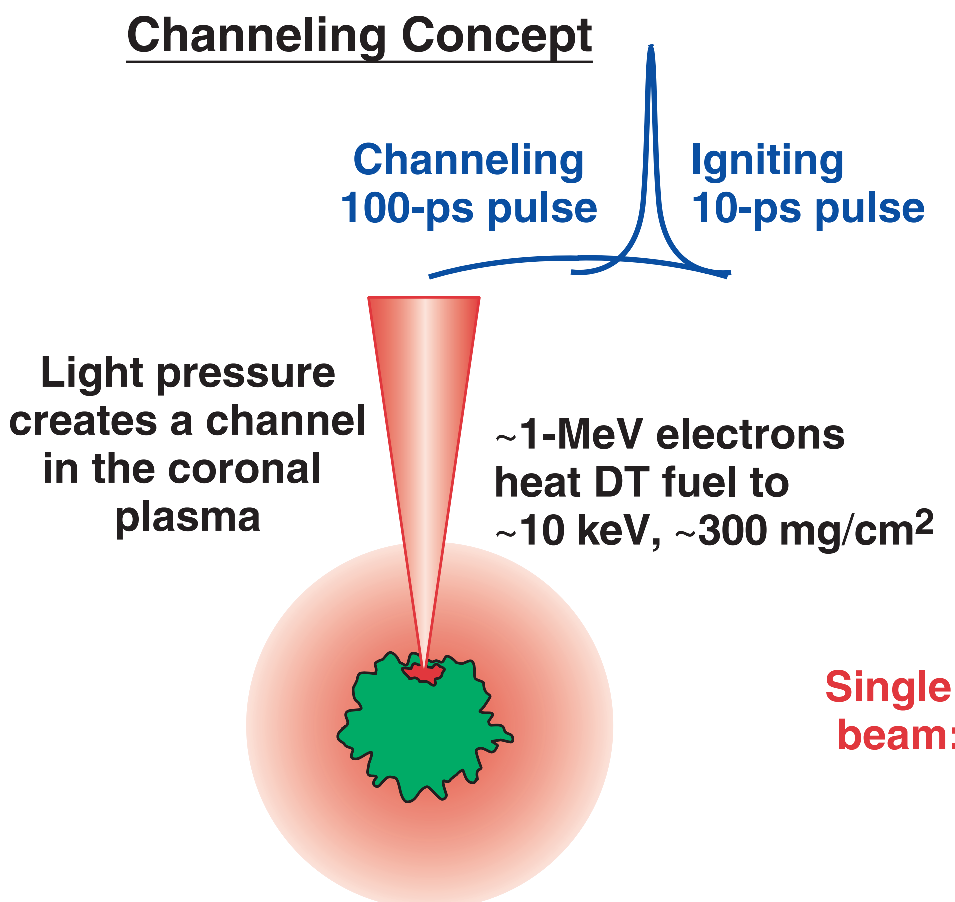


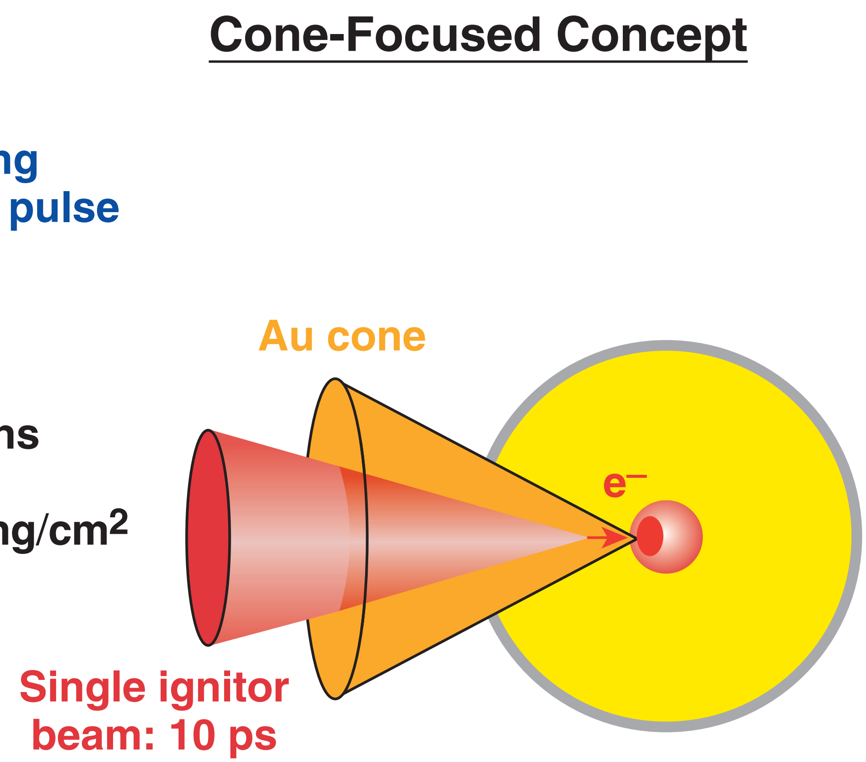
OMEGA EP
Laser Bay
(Sept. 2006)

I1636b

Fast Ignition

OMEGA EP will test two concepts for fast ignition; two techniques have been developed to reduce the distance that an electron beam must traverse

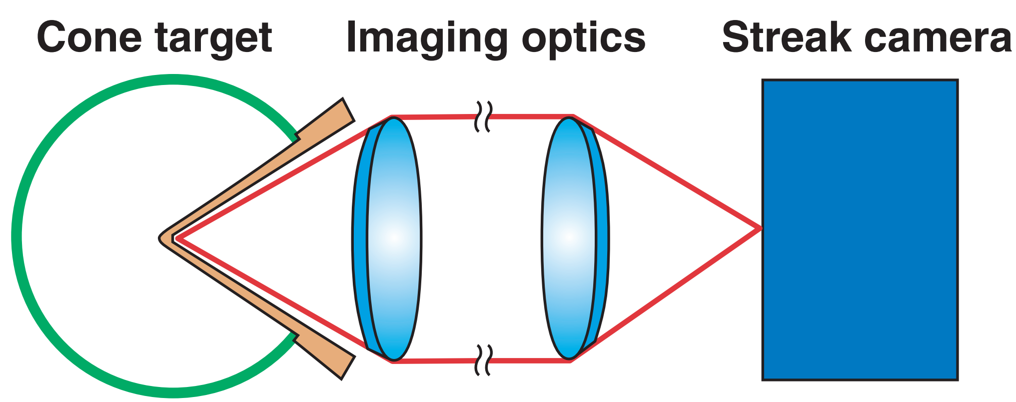


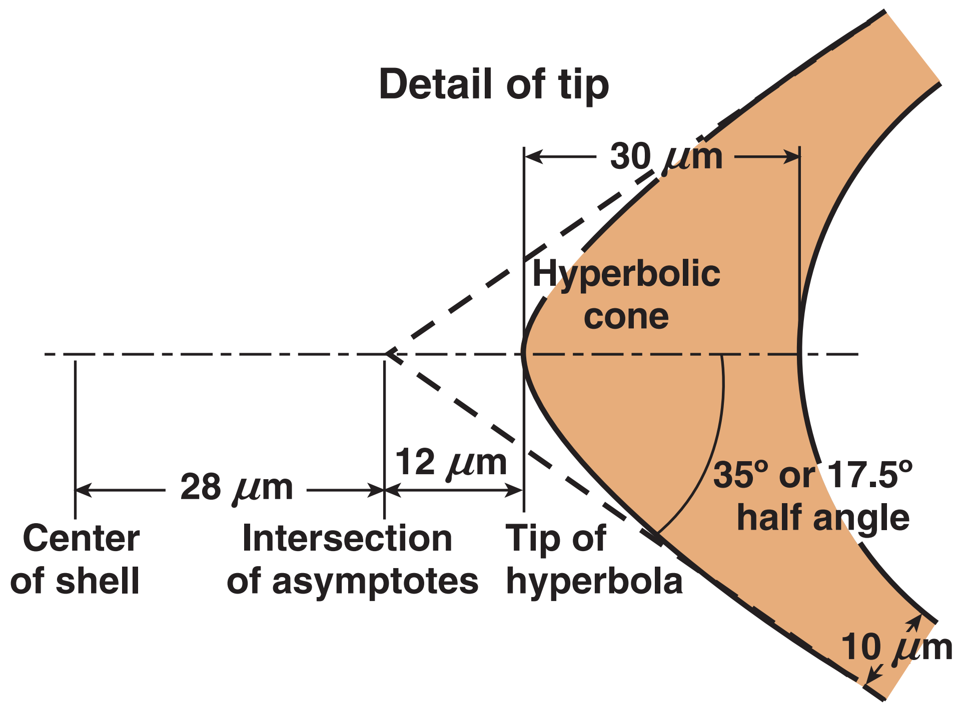


Integrated cryogenic fast-ignition experiments will begin in FY09

E11710j

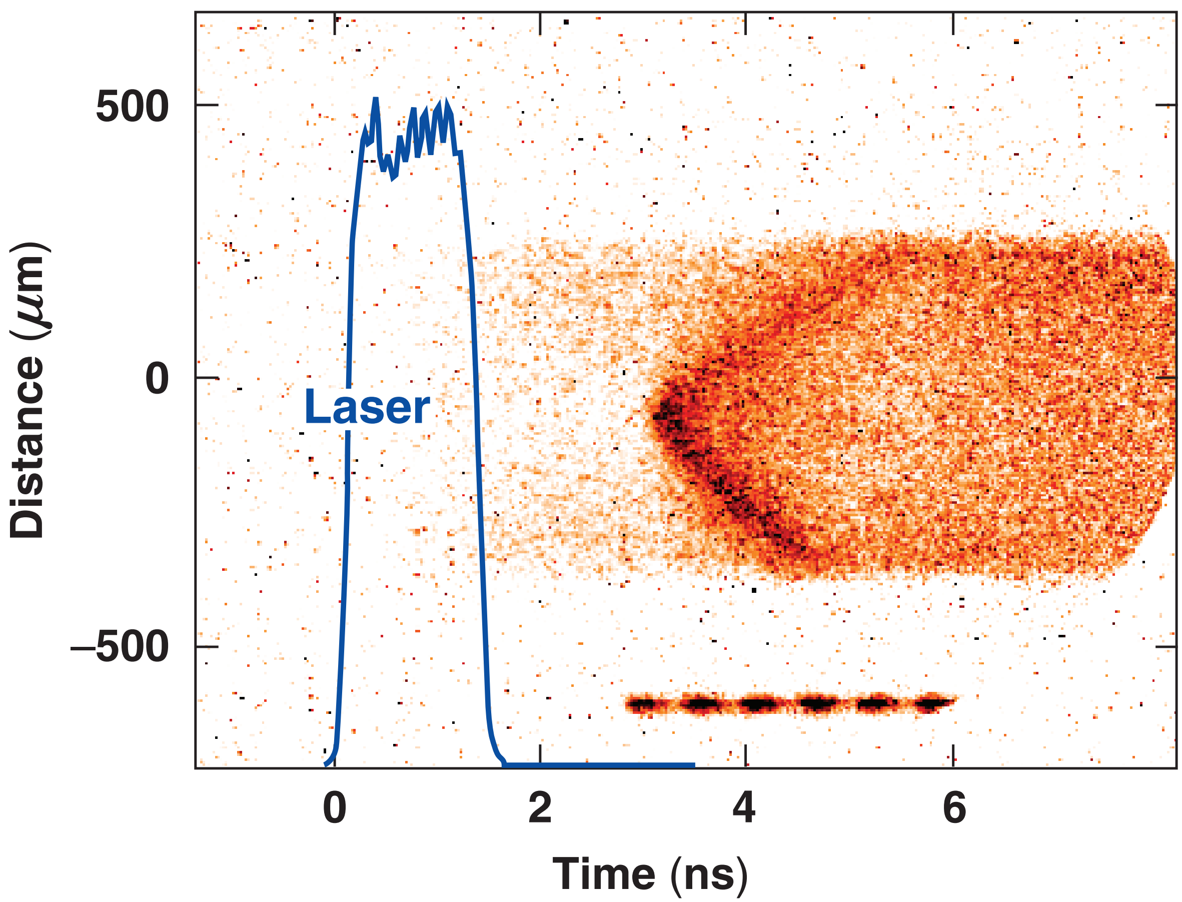
Streaked optical pyrometry (SOP) is used to observe the cone filling with plasma

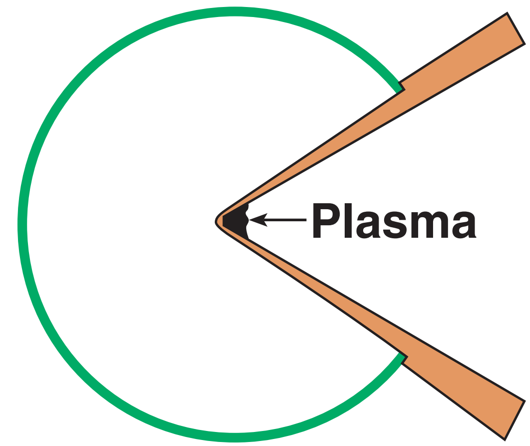




E13821a

The 70° cone shows a clean shock-breakout signal at the tip of the cone

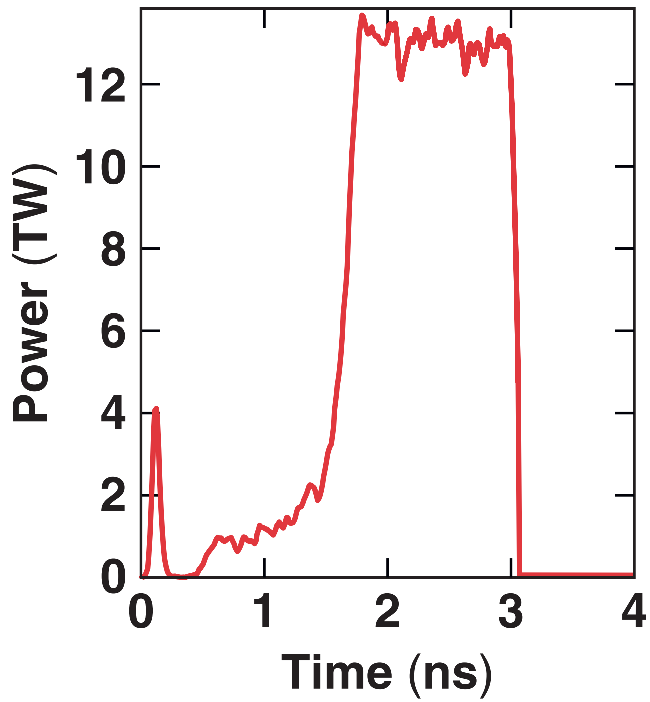


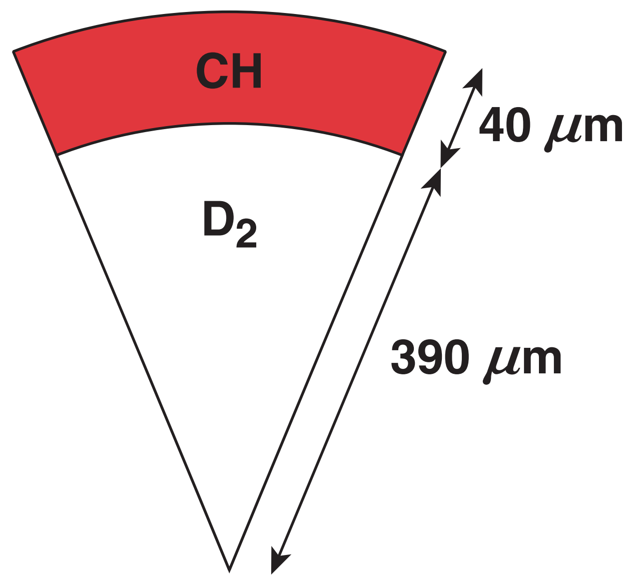


- Shot 38548, 1-ns pulse, 18 kJ, 48 beams, 24-μm CH shell

E13823a

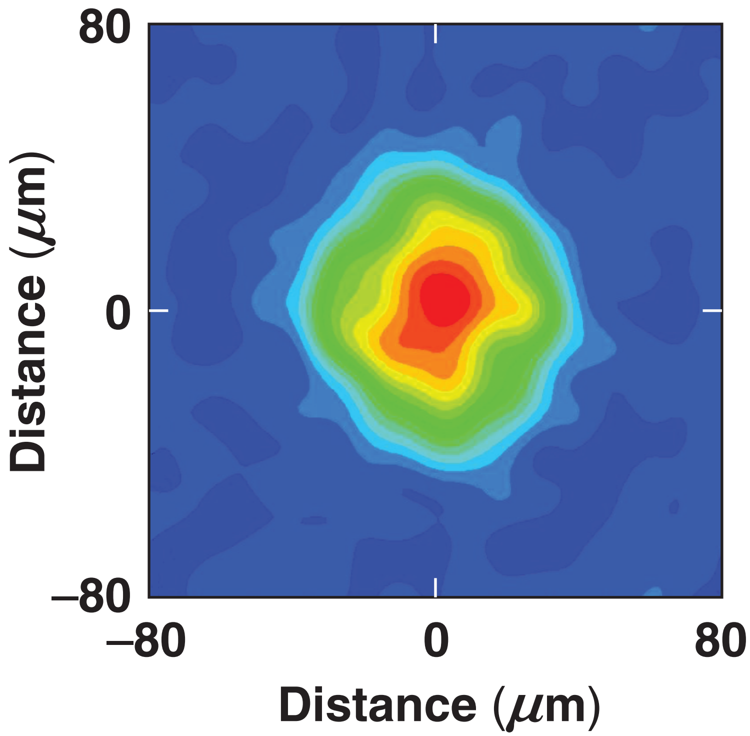
Low-adiabat, low-V_i experiments with CH targets are used to study fast-ignition fuel assemblies





$\alpha \approx 1.3$, $V_i \approx 2 \times 10^7$ cm/s

The measured areal densities (ρR) are the largest ever for laser-driven implosions



Areal densities	ρR (g/cm^2)
$\langle \rho R \rangle_p$ experiment DD fill, 25, 33 atm	0.13
$\langle \rho R \rangle_p$ experiment DHe_3 fill, 25, 33 atm	0.14
$\langle \rho R \rangle_n$ simulation averaged over NTD	0.145
$\langle \rho R \rangle_{max}$ simulation	0.28

X-ray image shows uniform core.

TC7385

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