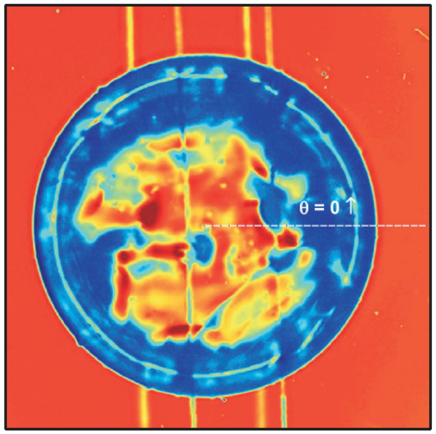
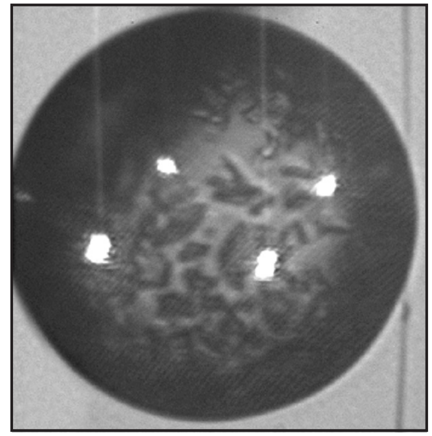
Status and Plans for OMEGA





Shot 33687 Experimental (α ~ 4)	YOC	Shot 33220 Experimental (α ~ 40)	YOC
Yield (1n): 4.6×10^9 TCC offset: 36 μm	23%	Yield (1n): 1.78×10^{11} 40 μm	~115%

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Forum on the Future of Fusion
Fusion Power Associates
Washington, DC
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Summary

LLE is making significant progress in direct-drive inertial confinement fusion research

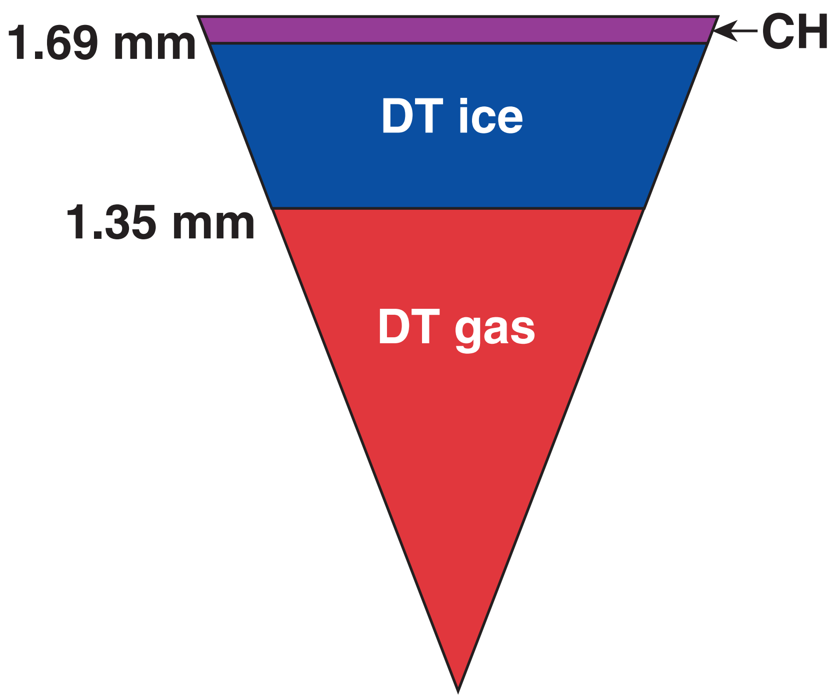
- Adiabat-shaping techniques will allow
  - lower-adiabat (higher-compression) implosions on OMEGA and
  - higher-gain target designs for the NIF.
- Cryogenic target experiments are showing promise.
  - Ice-surface roughnesses are approaching 1 μm rms, ignition specifications.
  - The first wetted-foam target has produced the highest cryogenic D_2 neutron yield.
  - 2-D simulations are in good agreement with experimental observations.
- OMEGA EP (two ps beams, 2.6 kJ each) will extend LLE’s research, including integrated fast-ignition experiments.

The NIF base-line direct-drive ignition target is a thick DT-ice layer enclosed by a thin CH shell

UR LLE

- Target designs are characterized by the isentrope parameter α:

$$\alpha = \frac{\text{Electron pressure}}{\text{Fermi-degenerate pressure}}$$



Laser energy	1.5 MJ
Pulse shape	$\alpha = 3$
Gain	45
Yield	2.5×10^{19}
ρR_{peak}	1.3 g/cm^2
$\langle T_i \rangle_n$	30 keV
Hot-spot CR	28
Peak IFAR	60

E11250

The OMEGA cryogenic implosion campaign is a staged program leading to verification of scaled-ignition performance with DT fuel by the end of FY05

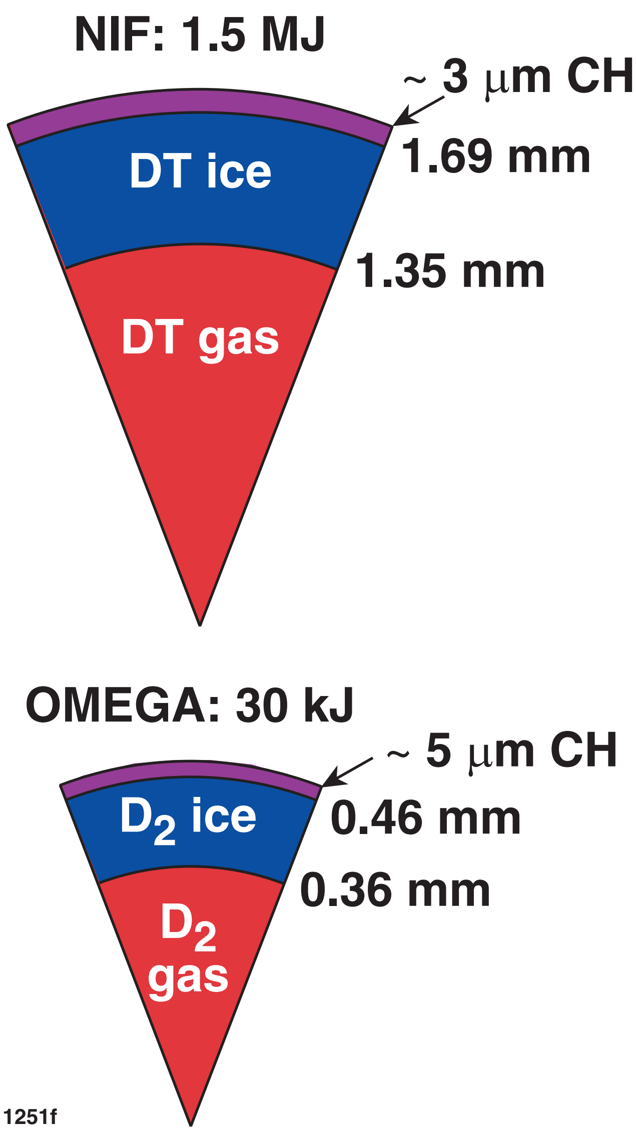
UR LLE

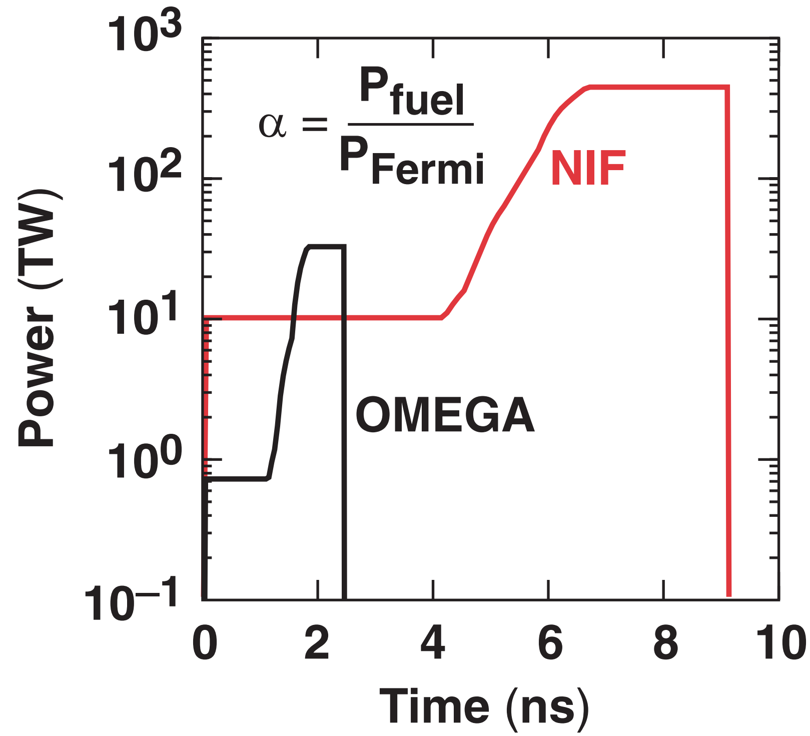
- The program is driven by three main objectives:
  - Validation of target performance for the lowest effective adiabat
  - Minimization and absolute characterization of DT cryogenic-layer roughness
  - Use of cryogenic DT targets in OMEGA implosion experiments

Most of the experimental work will be accomplished with D_2.

TC6458a

Smoother ice layers allow OMEGA cryogenic implosion campaigns to examine ignition-scaled targets at lower adiabats

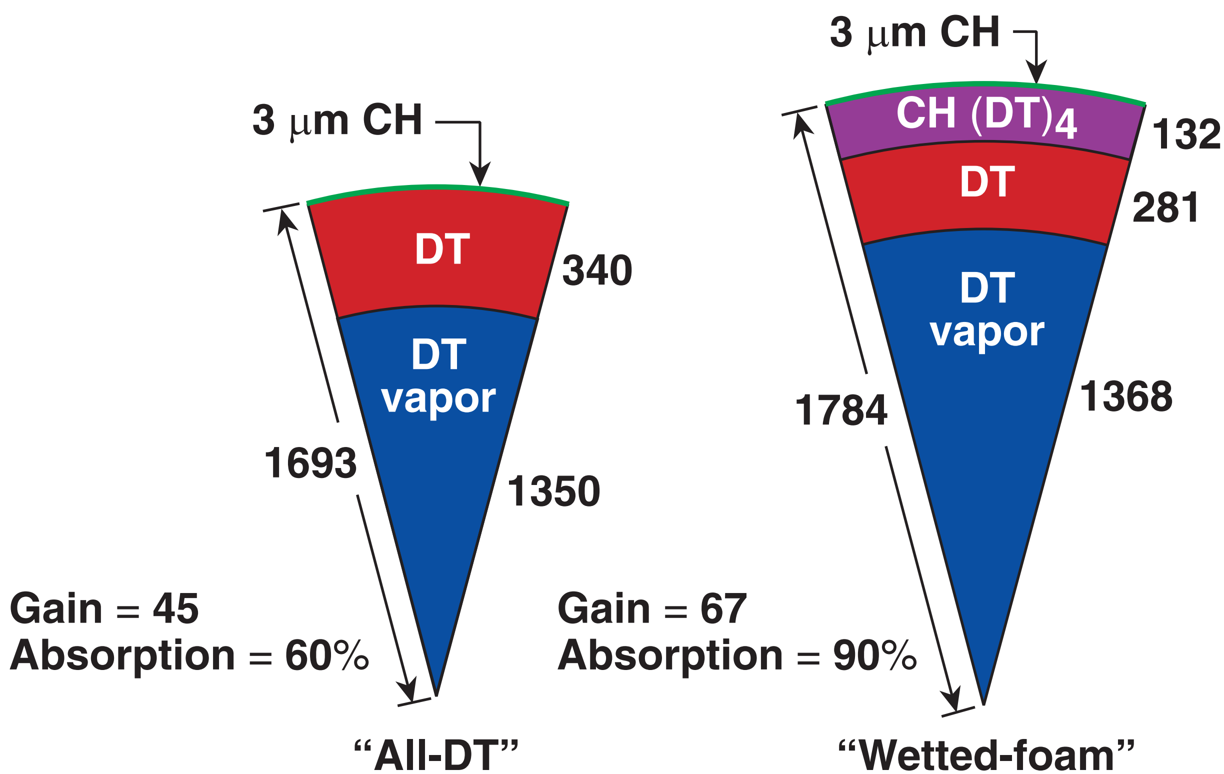




Energy ~ $radius^3$;
power ~ $radius^2$;
time ~ radius

E11251f

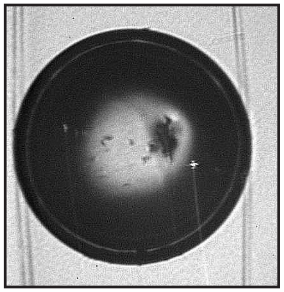
The OMEGA cryogenic implosion campaign is examining scaled-ignition target designs employing two ablator concepts

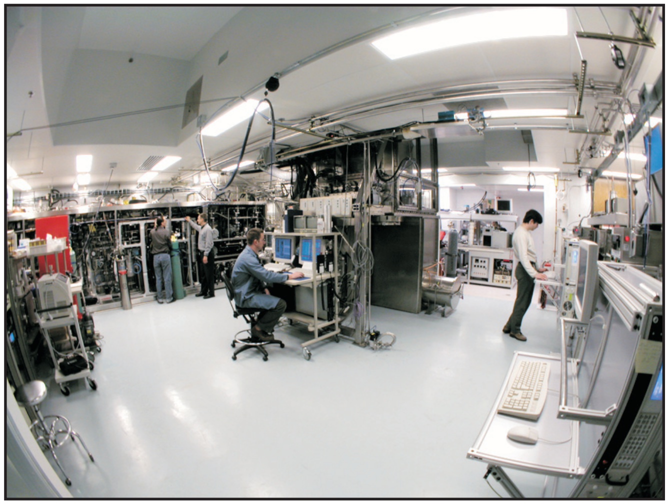


TC5787k

Cryogenic target implosions require significant engineering and development

- Cryogenic implosions have been carried out on OMEGA for ~3 years.
- Significant obstacles have been overcome
  - cryogenic target transport
  - target survival
  - target layer survival
- The final issue has been to minimize target vibration at shot time.





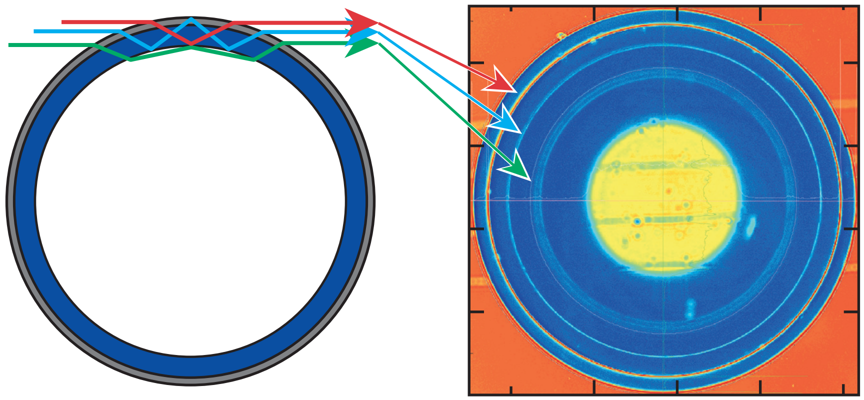
Fielding cryogenic targets is very difficult and requires a lot of time and effort.

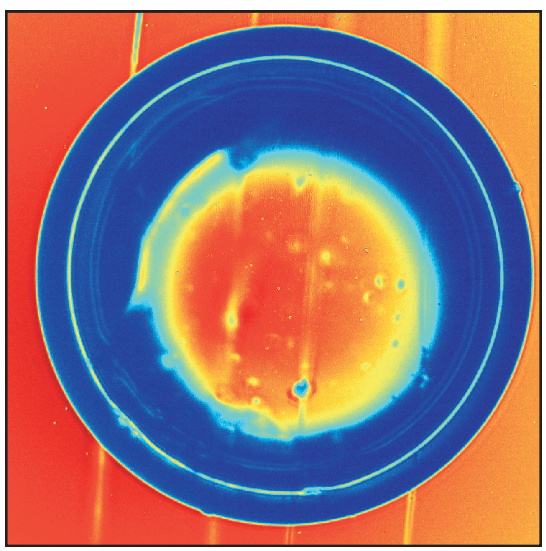
I1420a

Recent D_2-ice layers with IR heating are approaching the NIF 1-μm rms requirement

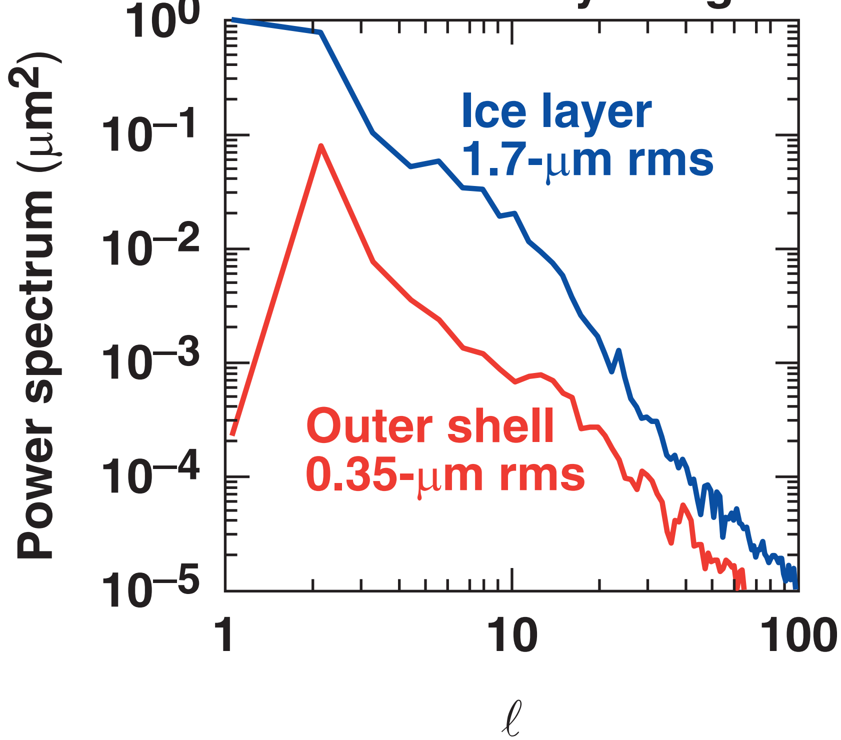
UR LLE

Surrogate target





Average spectra for 23 different angular views of the same cryo target



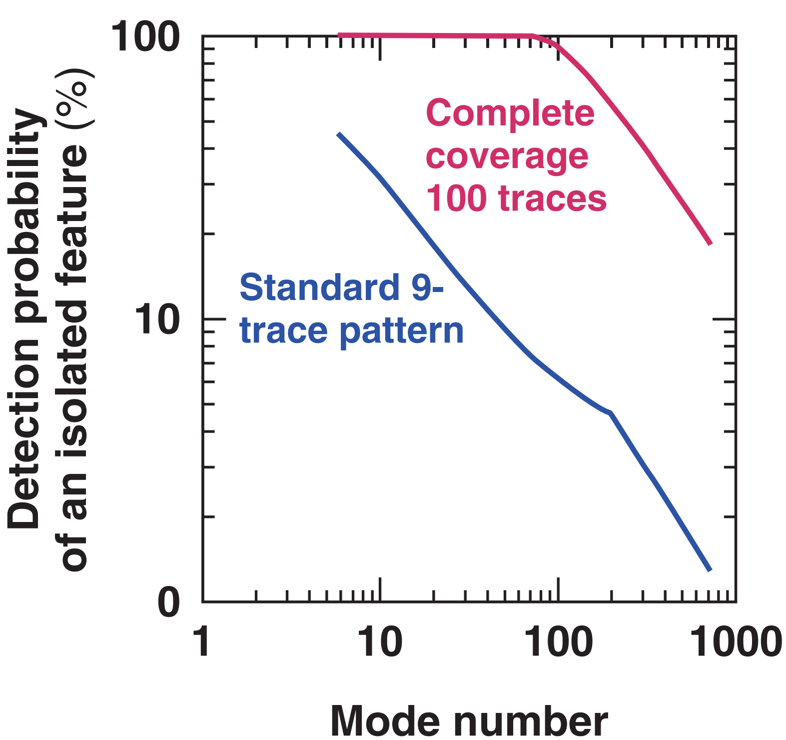
930-μm-diam OMEGA cryo target with 100-μm-D_2-ice layer and 3.5-μm-CH shell

E12272d

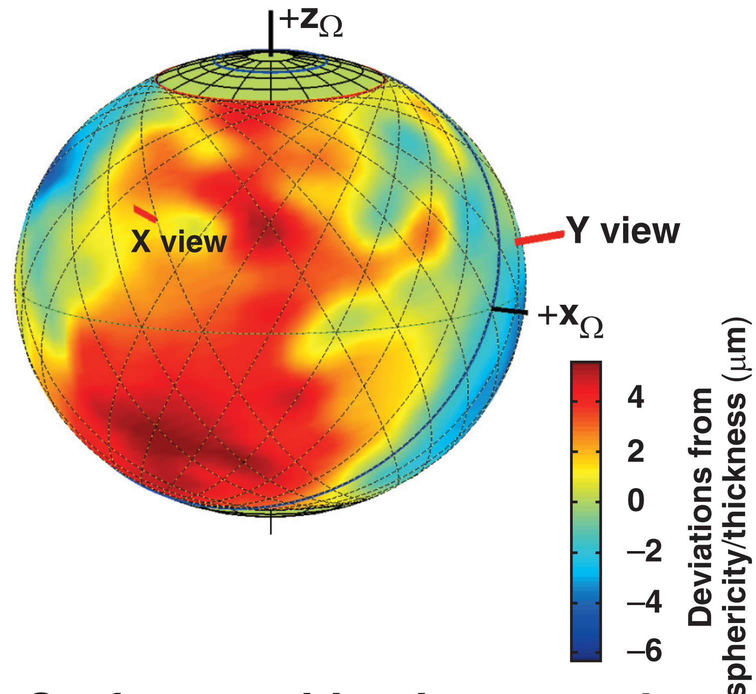
Accurate three-dimensional reconstructions for simulations require many sampling traces

GENERAL ATOMICS

(Courtesy of R. Stephens)



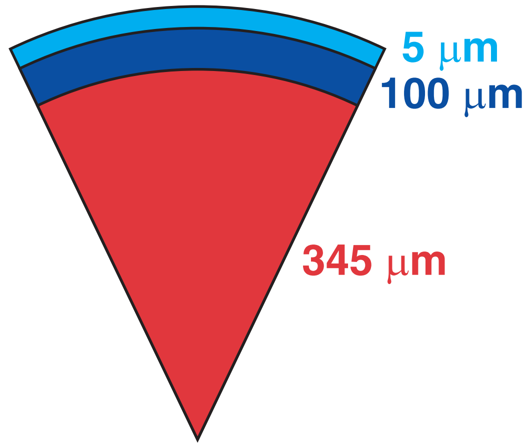
Topographical reconstruction

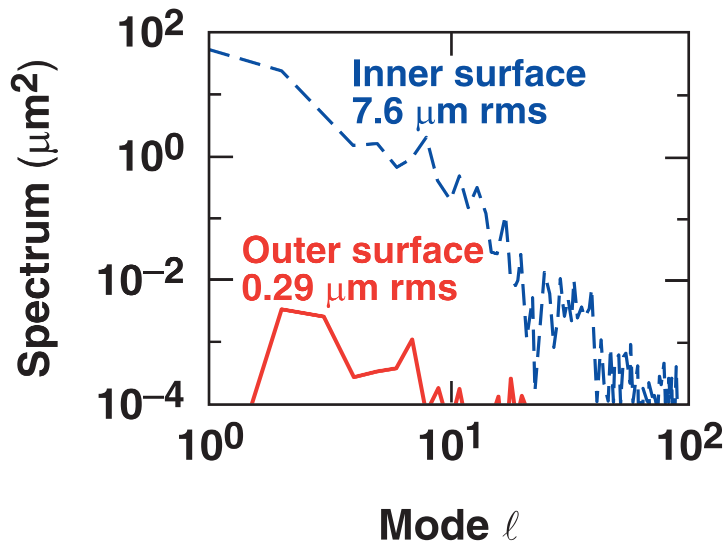


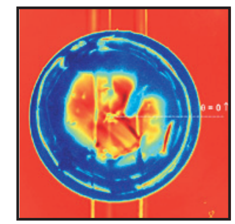
- Surface position is mapped onto sphere.
- Data are smoothed.
- Information for low-order modes is provided.

E12255b

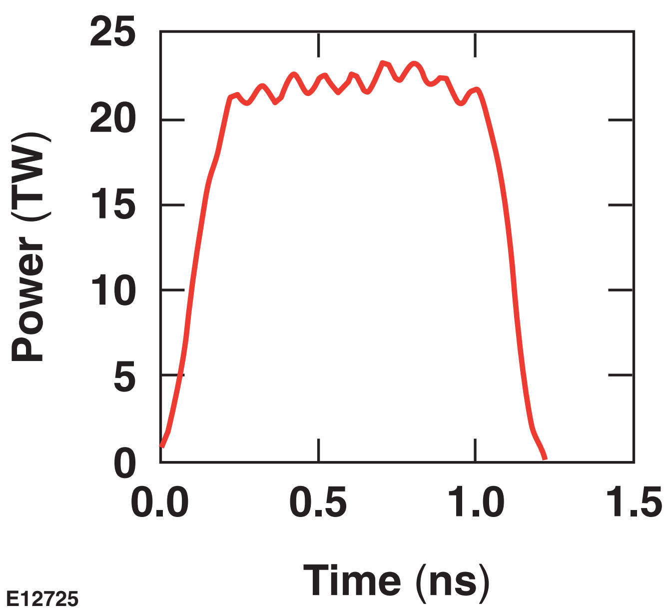
A high-adiabat drive pulse has been used to understand the effect of ice roughness on target performance

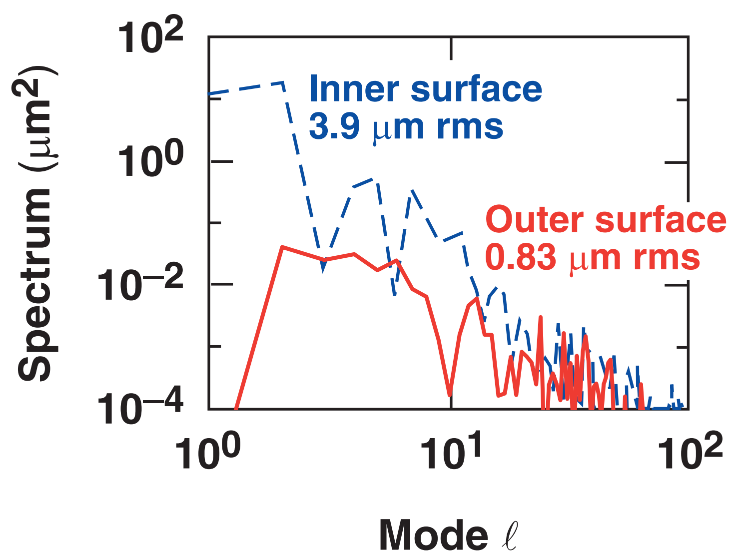


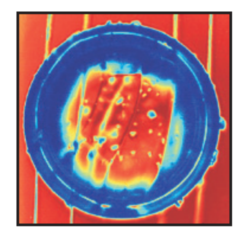




α ~ 25,
27% YOC
33413





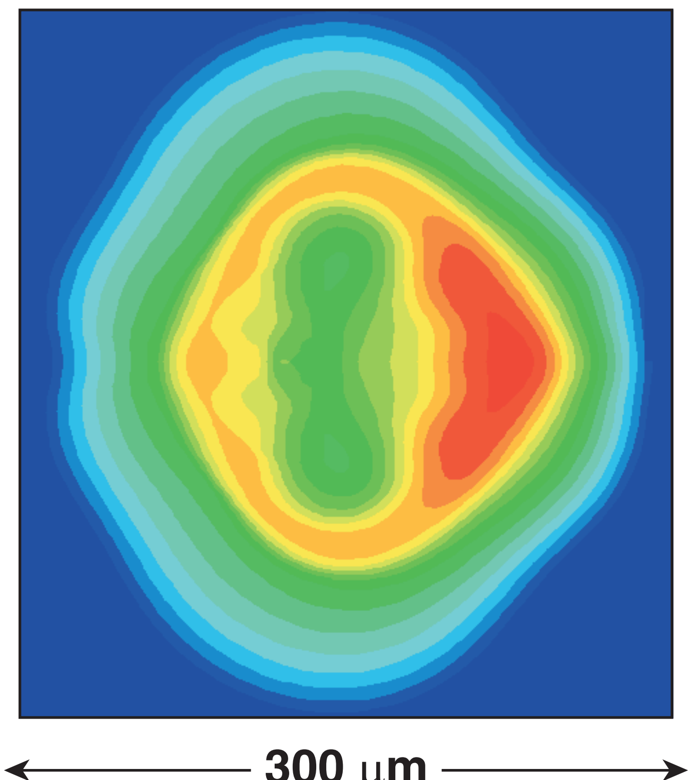


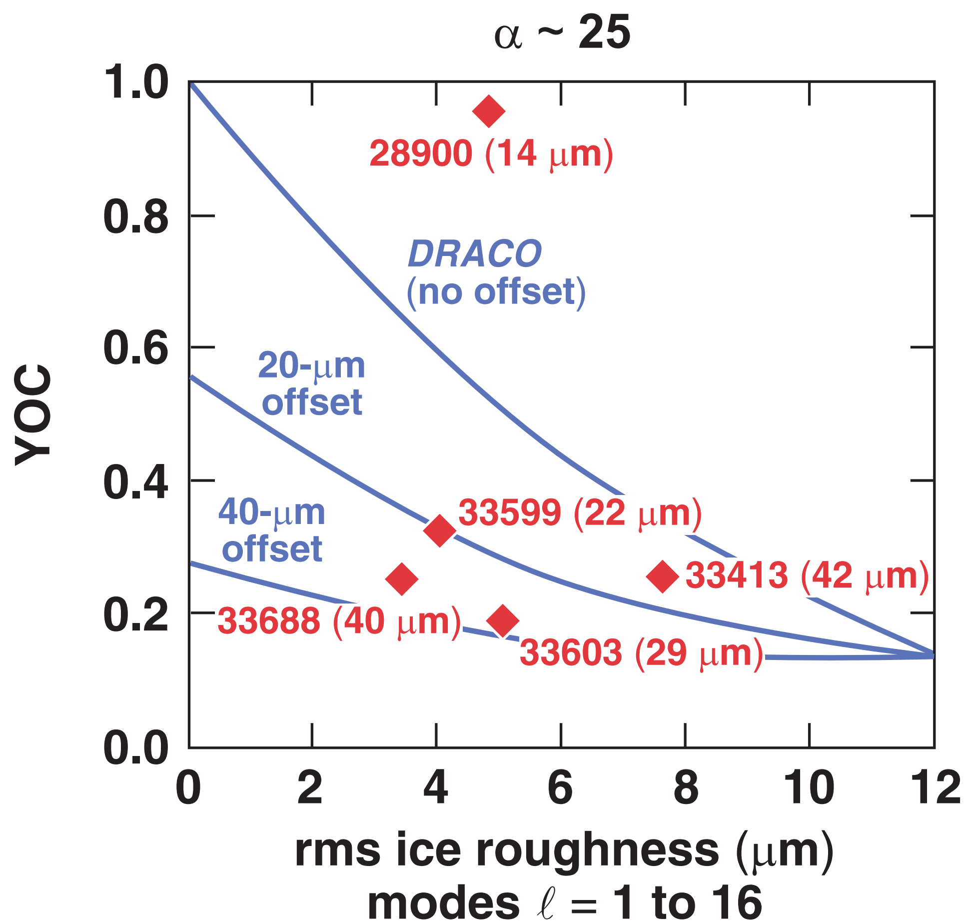
α ~ 25,
36% YOC
33599

E12725

There is good agreement between high-adiabat implosion performance and 2-D hydrocode simulations (*DRACO*)

Shot 33413



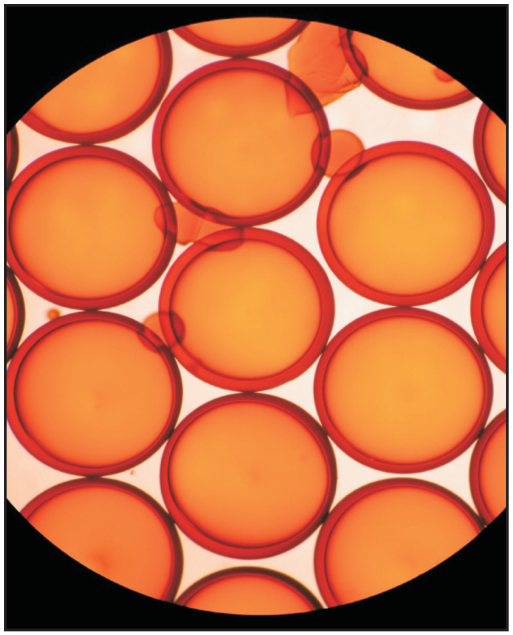


TC6108b

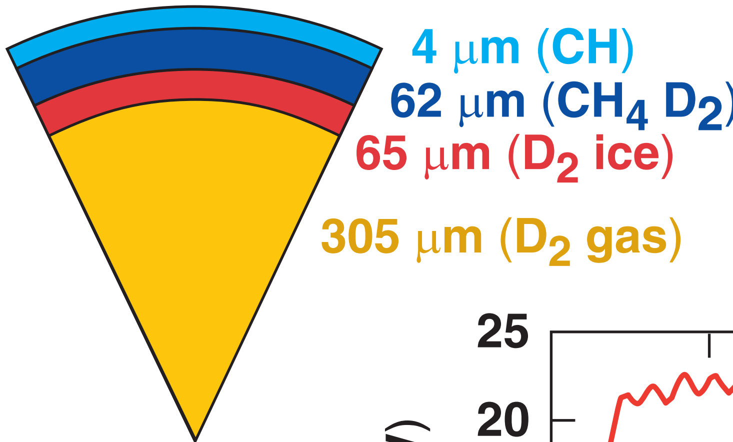
Research at GA has produced a variety of dry foams for ICF implosion experiments on OMEGA

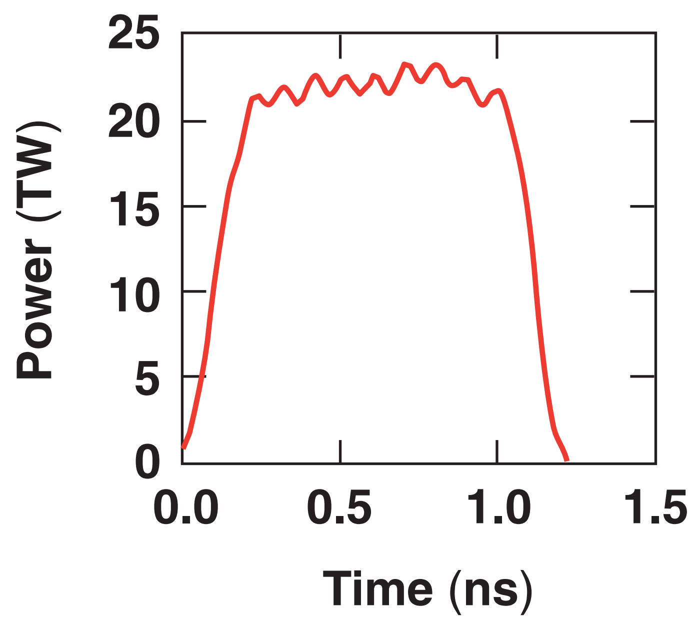
GENERAL ATOMICS

R/F foam shells in liquid



OMEGA target

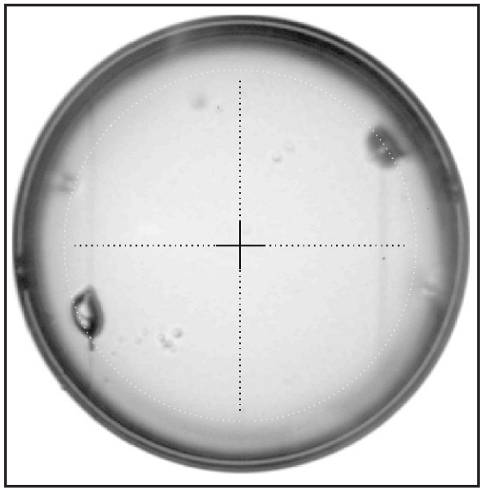


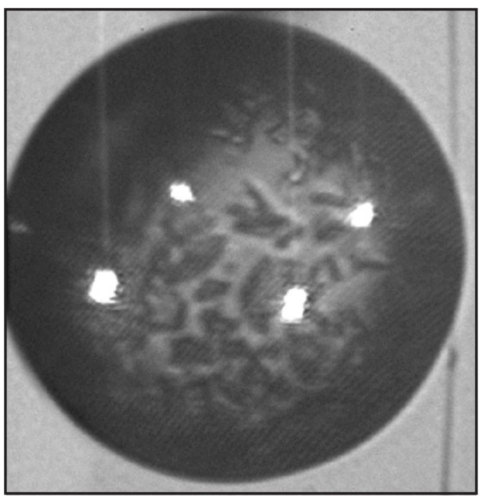


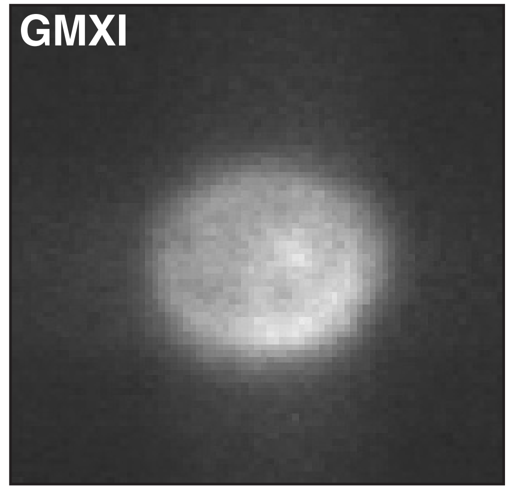
An increasing fraction of experiments at LLE will use wetted-dry-foam shells.

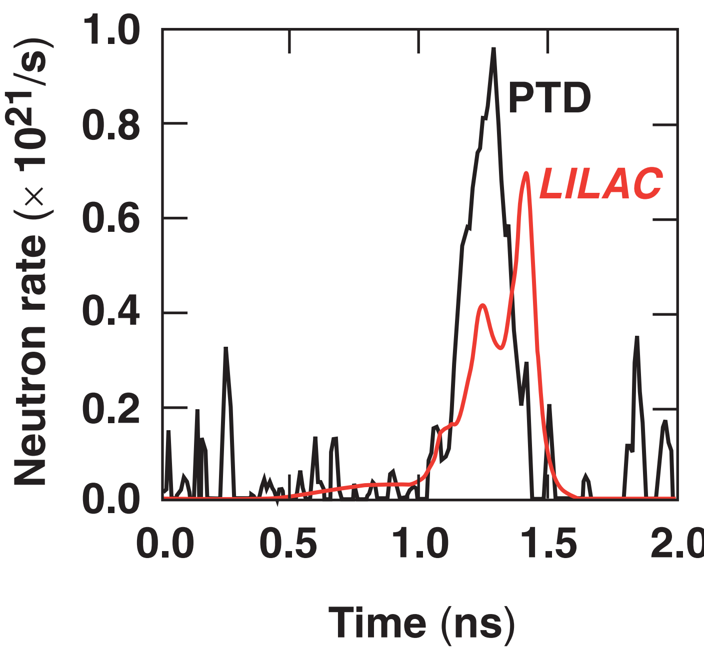
TC6464a

The first OMEGA cryogenic wetted-foam-target implosion produced a surprisingly high cryogenic neutron yield









Experiment:

$Y_{1n} = 1.74 \times 10^{11}$ (114%)

$Y_{2n} = 3.5 \times 10^{8}$ (30%)

$T_{ion} = 5.2$ keV

LILAC

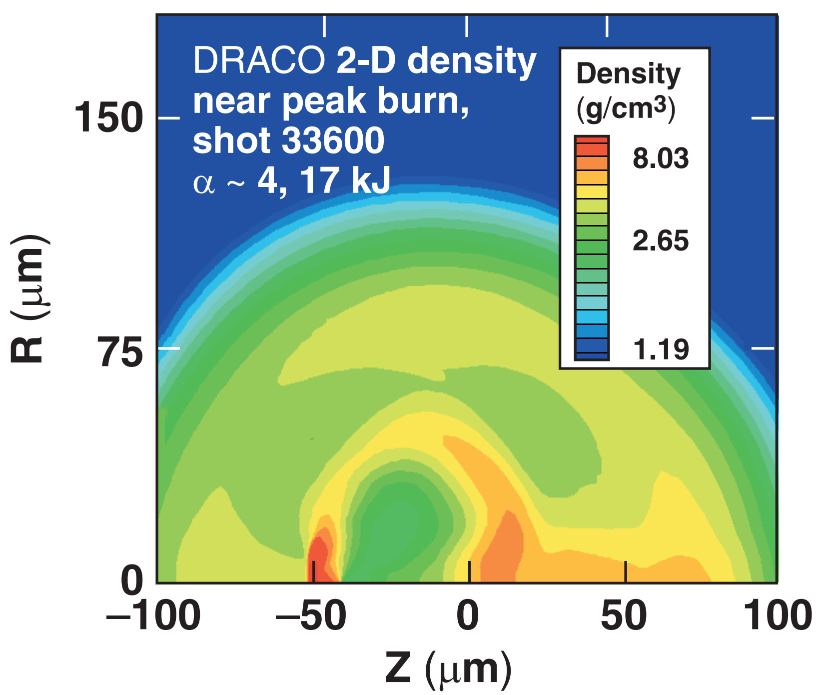
$Y_{1n} = 1.5 \times 10^{11}$

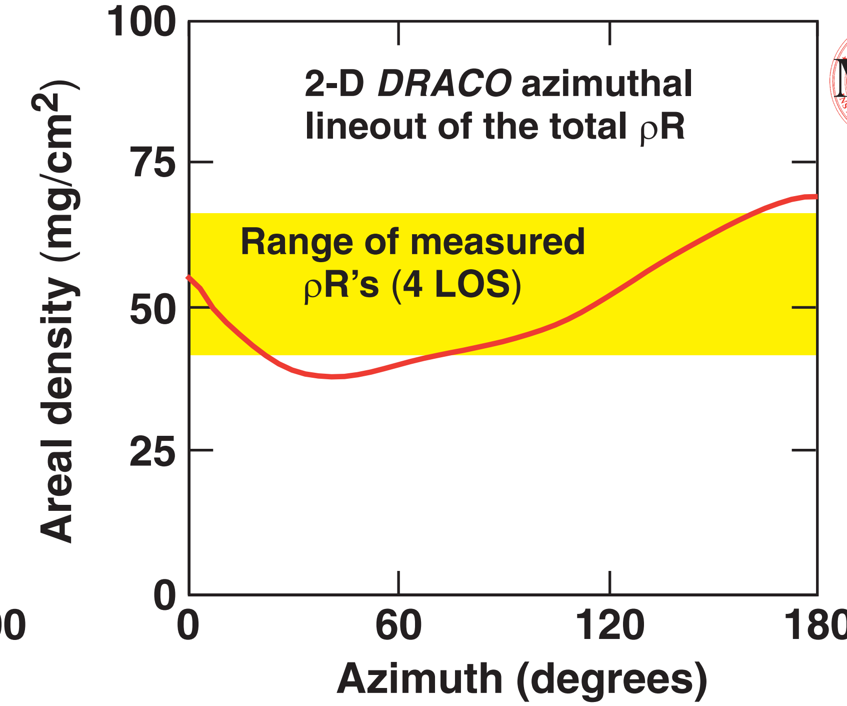
$Y_{2n} = 1.2 \times 10^{9}$

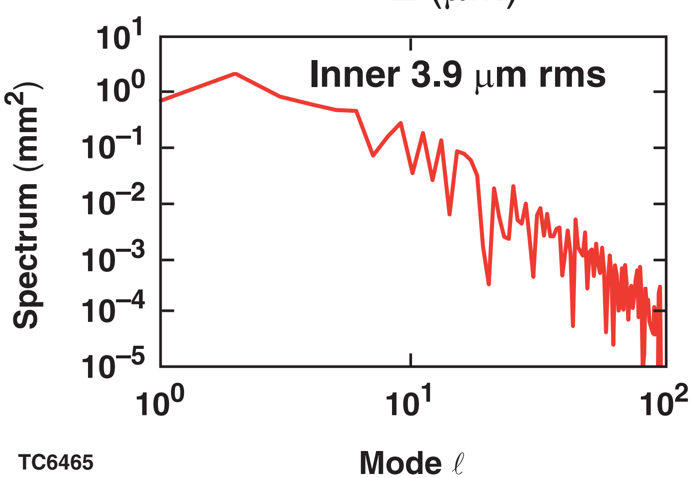
$T_{ion} = 2.7$ keV

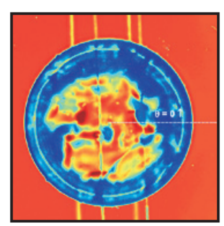
TC6460a

2-D *DRACO* demonstrates good agreement in predicting target performance for shot 33600 ($\alpha \sim 4$)









$\alpha \sim 4$
16% YOC
33600

	Expt	1-D	2-D
Y_{1n}	4.30×10^9	2.68×10^{10}	5.85×10^9
Y_{2n}	4.43×10^7	1.40×10^9	5.97×10^7
$\langle\rho R\rangle$	52	63	55
T_{ion}	2.7	1.6	1.4

TC6465

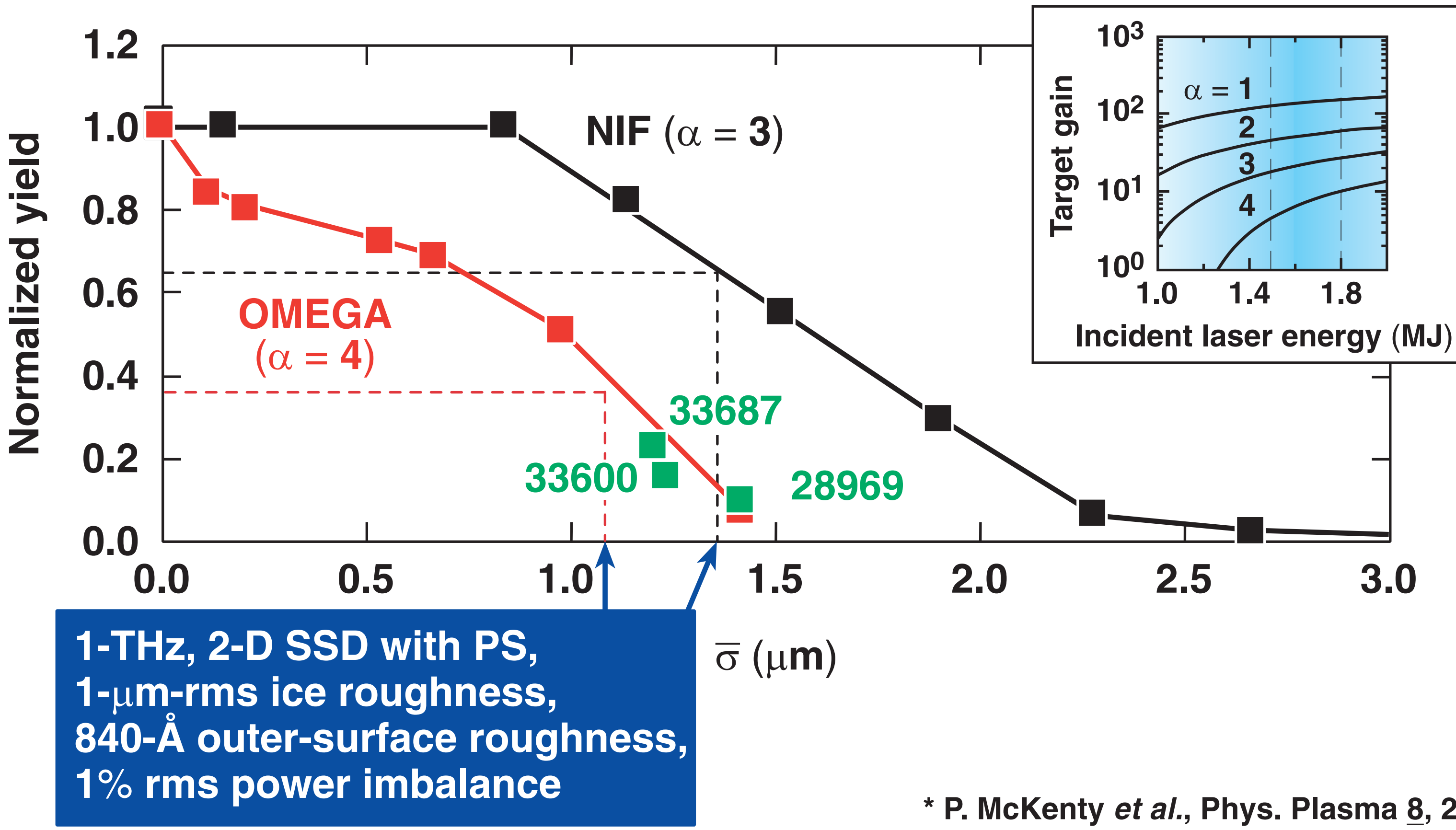
A stability analysis* of the $\alpha = 4$ design defines the ignition-scaling performance window for cryogenic implosions

UR LLE

- The NIF gain* and OMEGA yield can be related by

$$\bar{\sigma}^2 = 0.06\,\sigma^2_{\ell<10} + \sigma^2_{\ell\geq10},$$

where the σ_ℓ's are the rms amplitudes at the end of the acceleration phase.

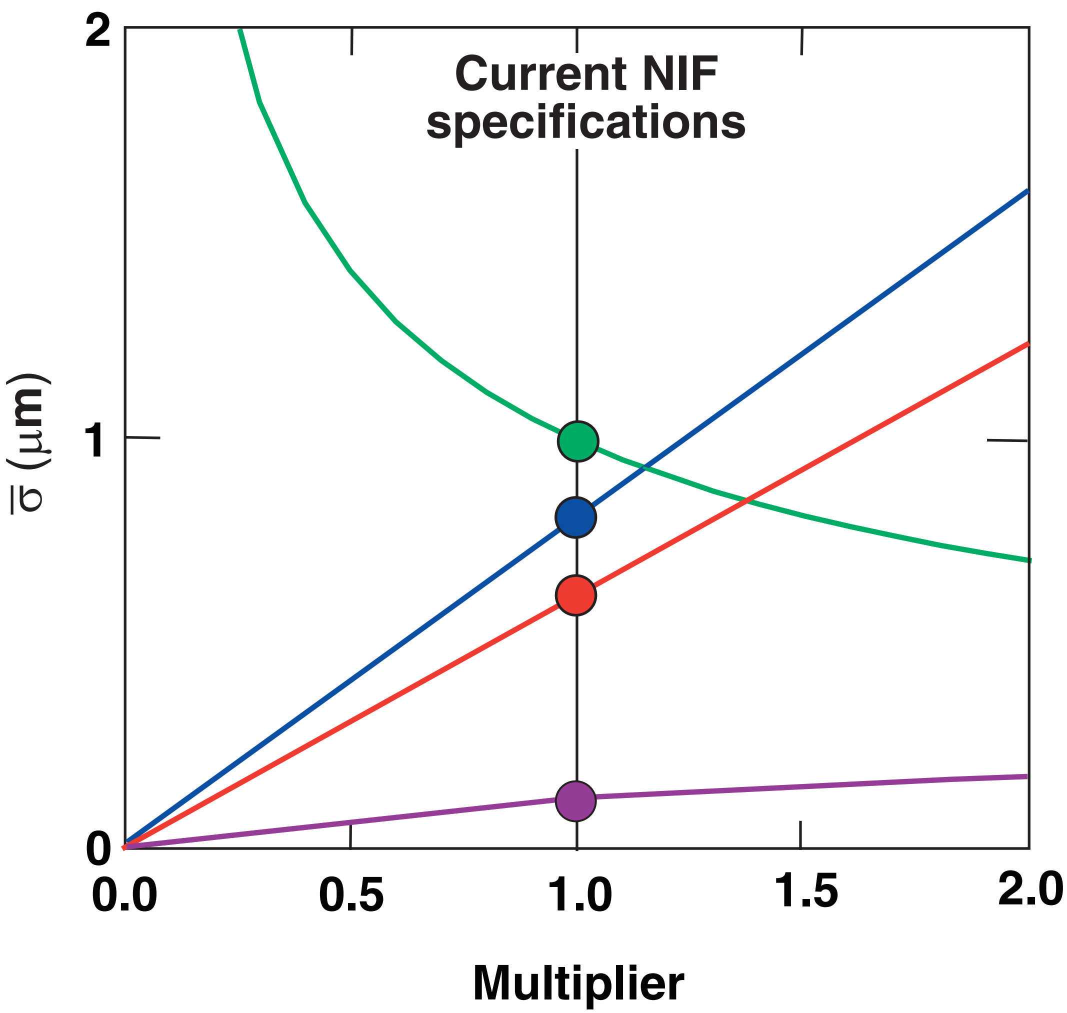


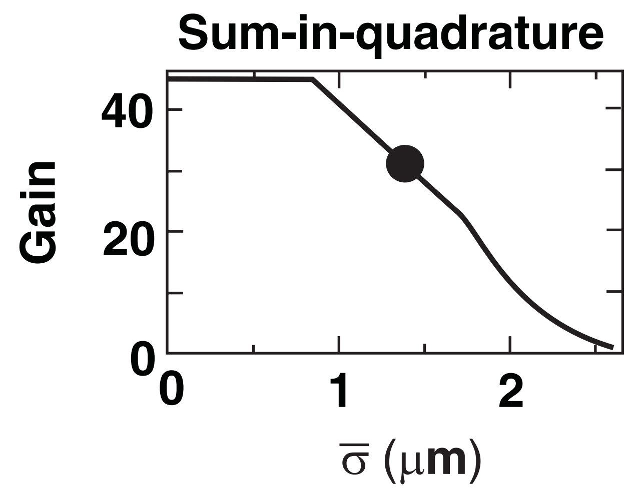
* P. McKenty *et al.*, Phys. Plasma 8, 2315 (2001).

E12008g

Scaling gain with $\bar{\sigma}$ allows the formation of a global nonuniformity budget for the direct-drive point design

UR LLE





Imprint

- Applied SSD bandwidth (2 color cycle × 1 THz)
- On-target power imbalance (× 2% rms)
- Inner-surface roughness (× 2-μm rms)
- Outer-surface roughness (× 80 nm)

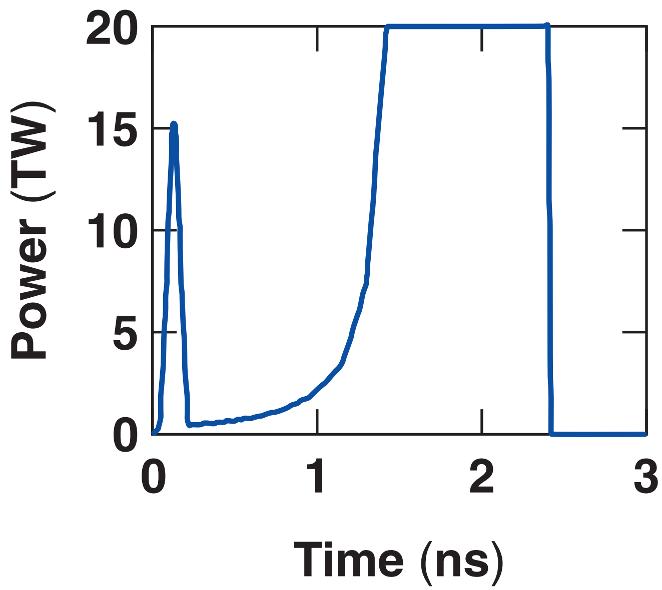
TC5577a

Adiabat shaping reduces ablative Rayleigh–Taylor growth[1]

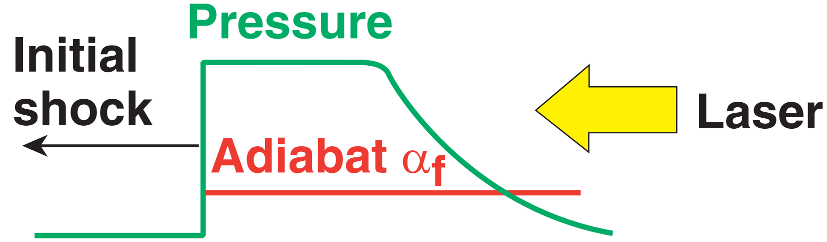
For DT foils:[2] $\gamma_{RT} = 0.94\sqrt{kg} - 2.6\ kV_a$, where $V_a \sim \alpha^{3/5}$.

$$\alpha = \frac{P_{fuel}}{P_{Fermi}}$$

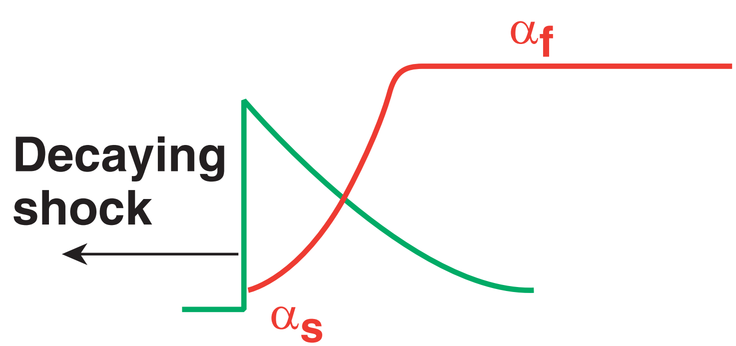
$\alpha = 2$



- $t = 0$ Picket creates a strong shock.
- $t = t_p$ Rarefaction wave (RW) is launched at $t = t_p$.



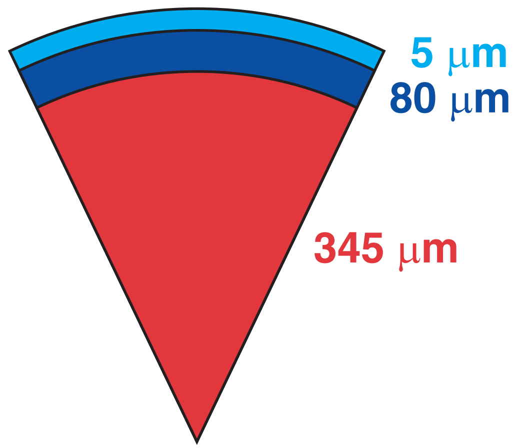
- $t = t_{RW}$ RW meets the shock.
- $t > t_{RW}$ Shock strength decreases in time.

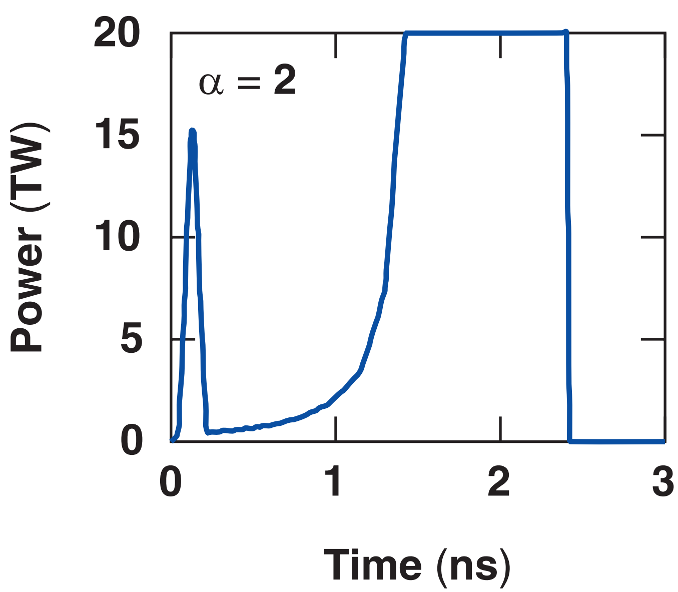


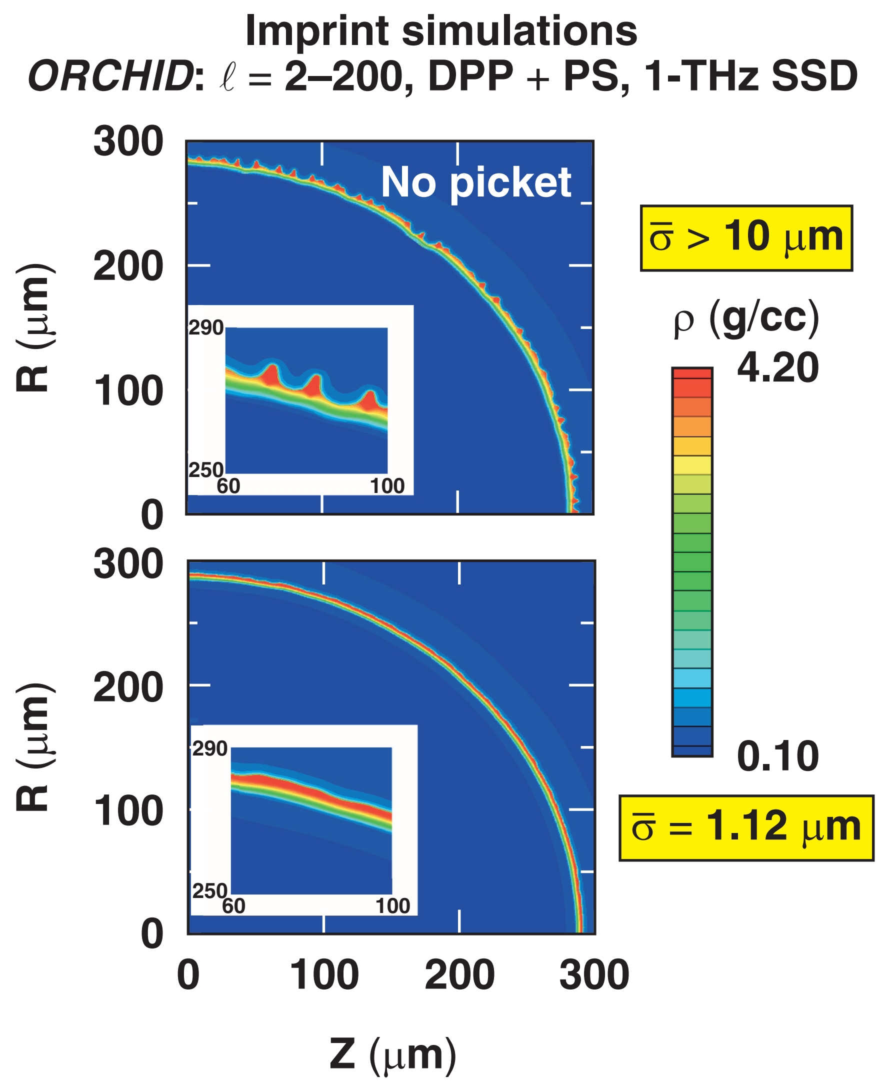
[1] V. N. Goncharov *et al.*, Phys. Plasmas 10, 1906 (2003).
[2] R. Betti *et al.*, Phys. Plasmas 5, 1446 (1998).

TC6372a

Picket results have led to examining lower-adiabat, NIF and OMEGA-scaled ignition designs



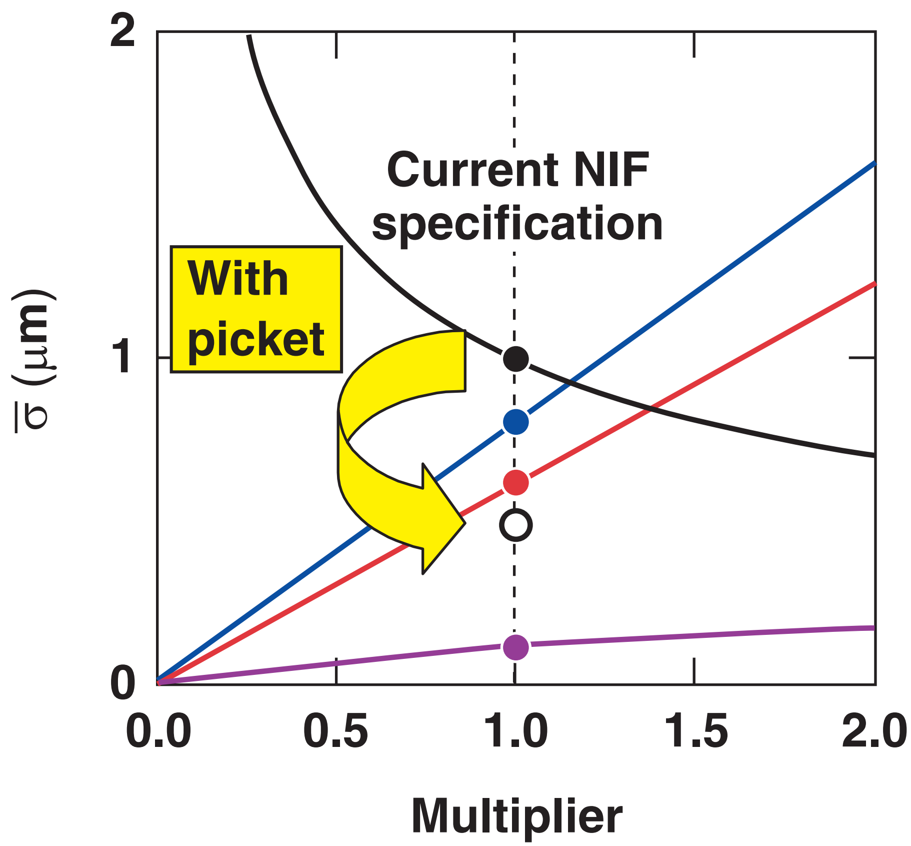


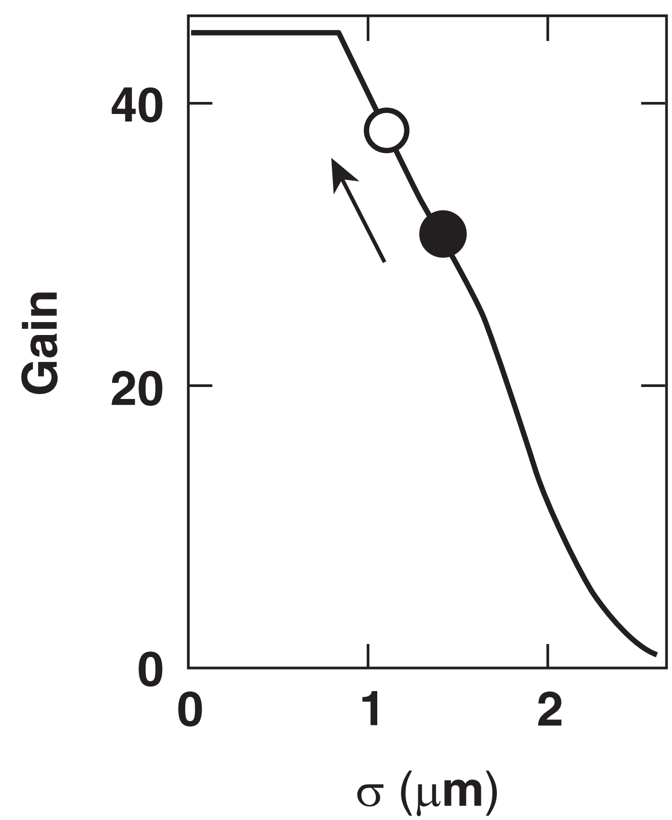


Significant effort will be devoted to picket implosions in FY04.

TC6341a

Direct-drive target stability is dramatically improved when adiabat shaping is applied

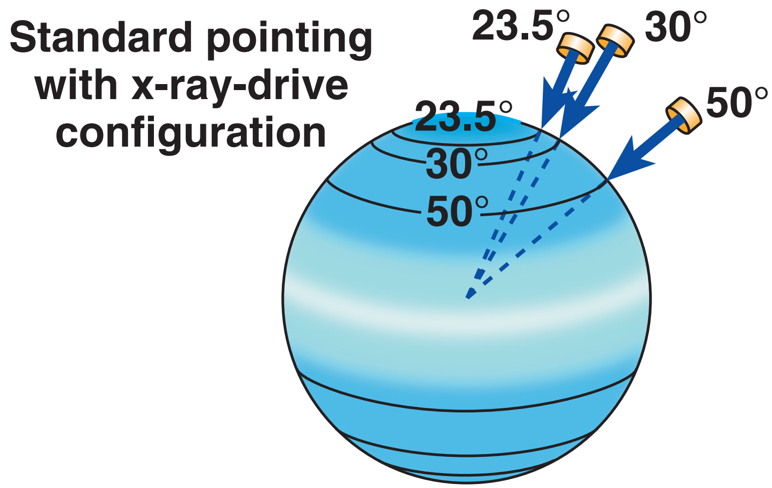


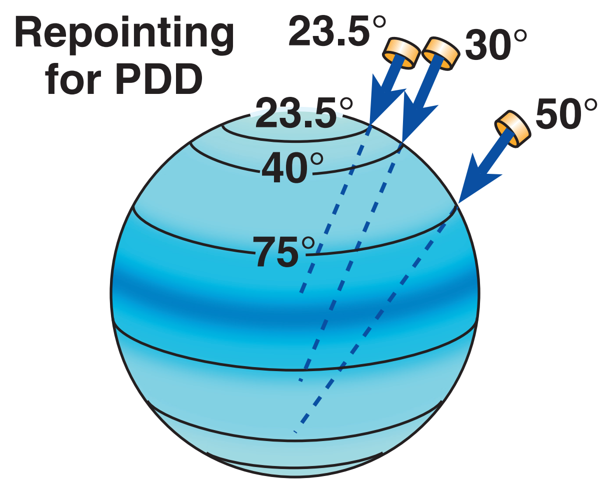


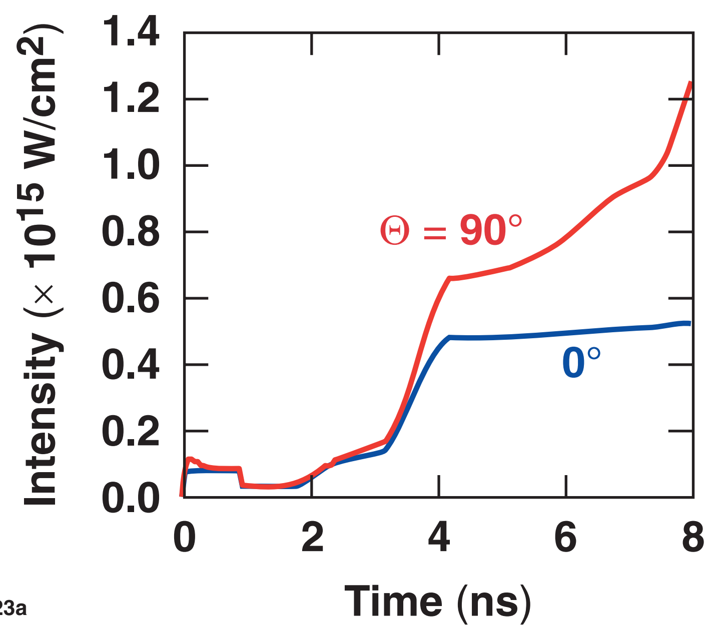
The benefit of pickets has been confirmed in NRL and LLNL simulations.

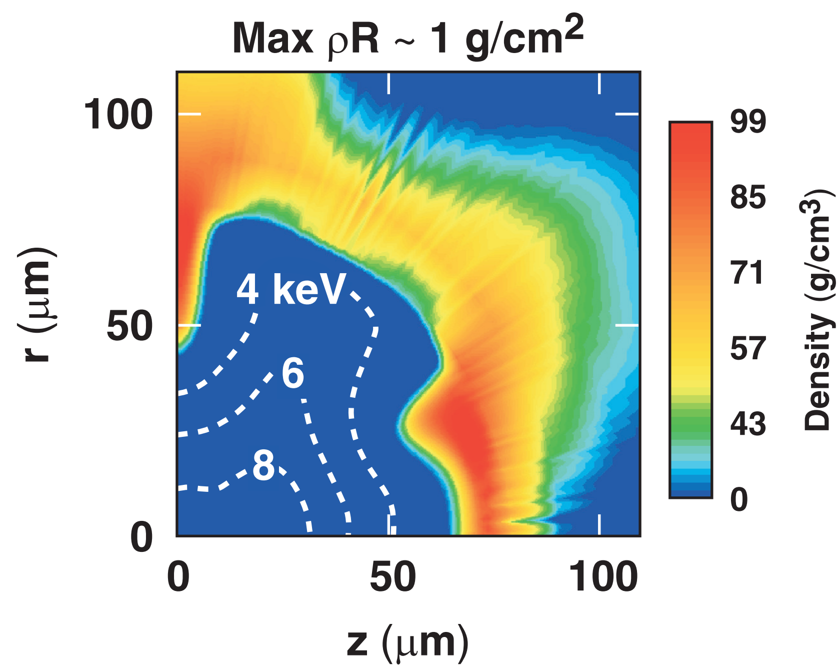
TC6339b

Polar-direct-drive simulations for the NIF are starting to show the onset of hot-spot formation







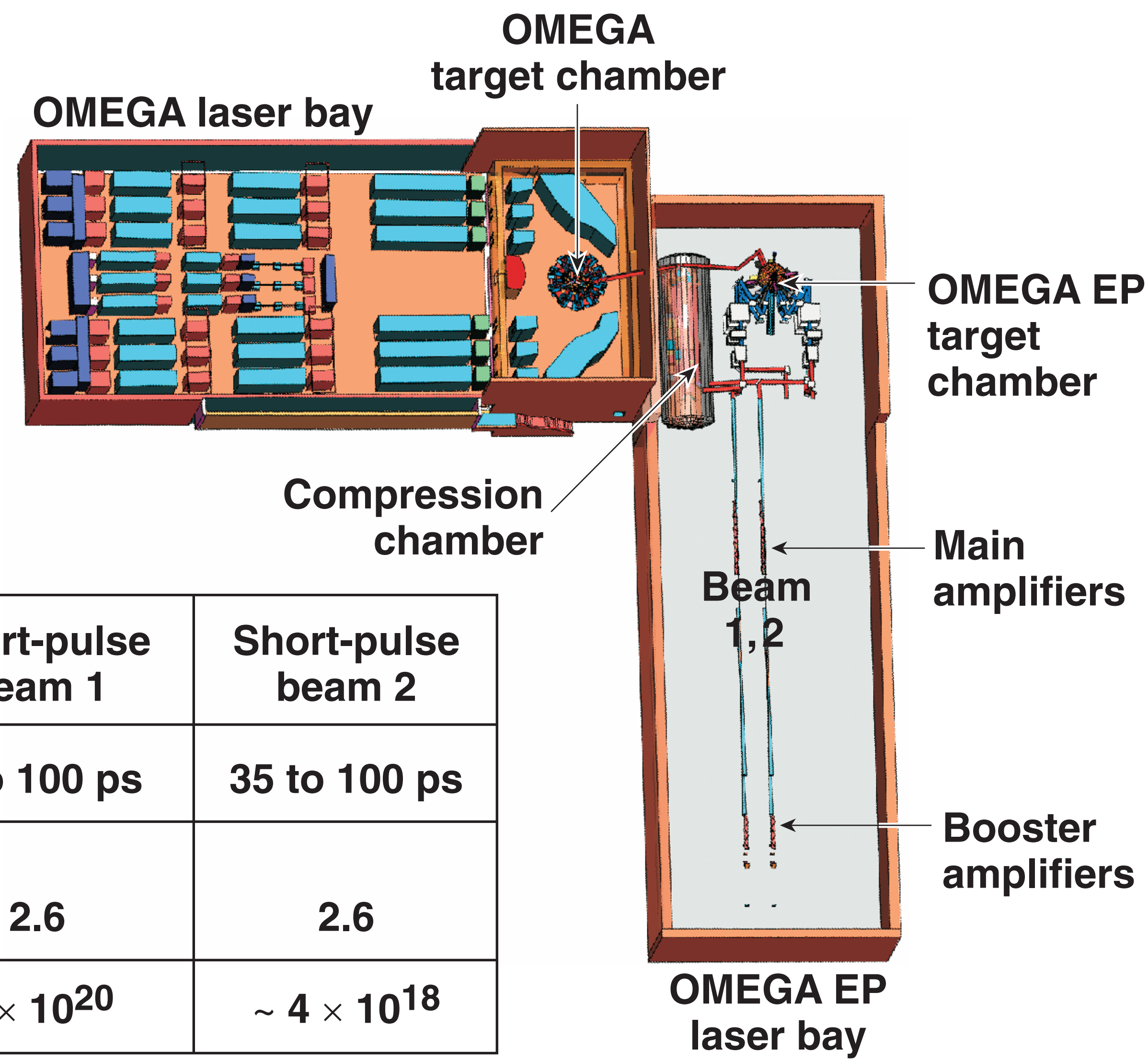


I1423a

OMEGA EP

The OMEGA EP beams will be located next to the existing OMEGA facility

UR LLE

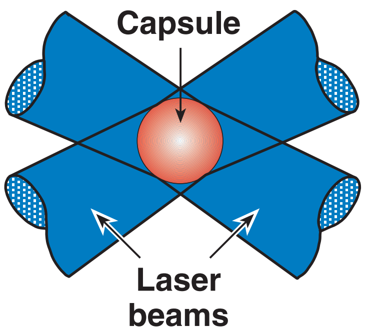


Short-pulse performance	Short-pulse beam 1	Short-pulse beam 2
Short pulse (IR)	1 to 100 ps	35 to 100 ps
IR energy on-target (kJ)	2.6	2.6
Intensity (W/cm^2)	6×10^{20}	~ 4×10^{18}

G5546h

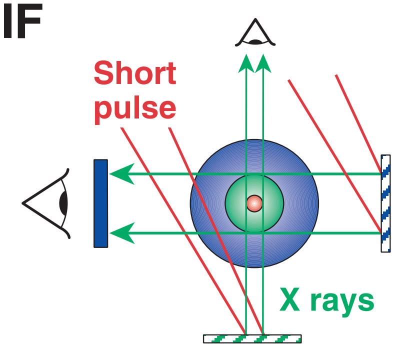
OMEGA EP will be an important new tool in LLE's experimental arsenal

- Significant progress has been made toward "hot-spot" ignition.

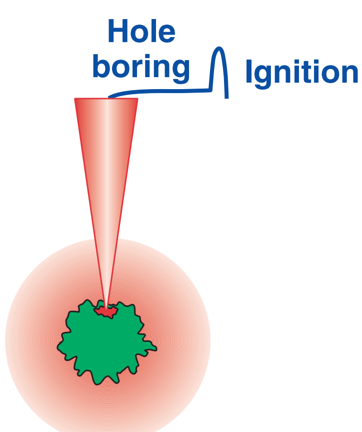


Diagnostic capability within existing OMEGA target chamber

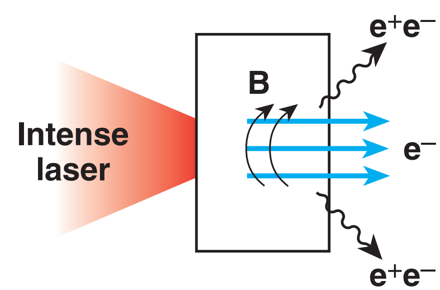
- Devlopment of radiographic diagnostic capability for HEDP and the NIF



- Validation of "fast ignition" with scaled cryogenic capsules



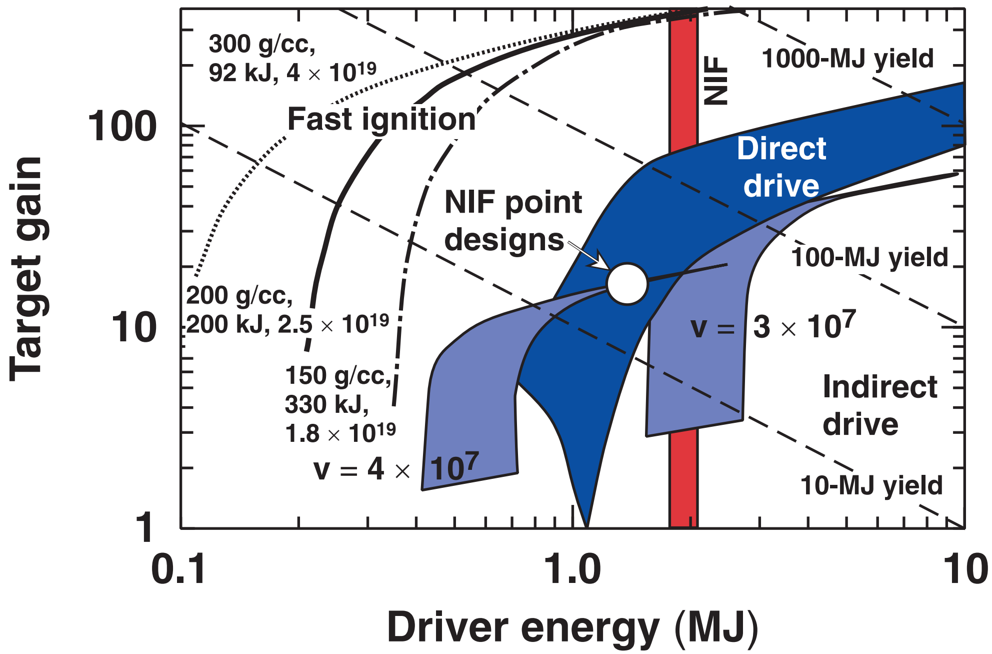
- Ultrahigh-intensity research capabilities



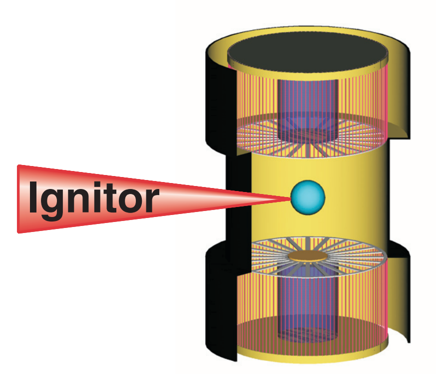
Electron acceleration + B-field generation

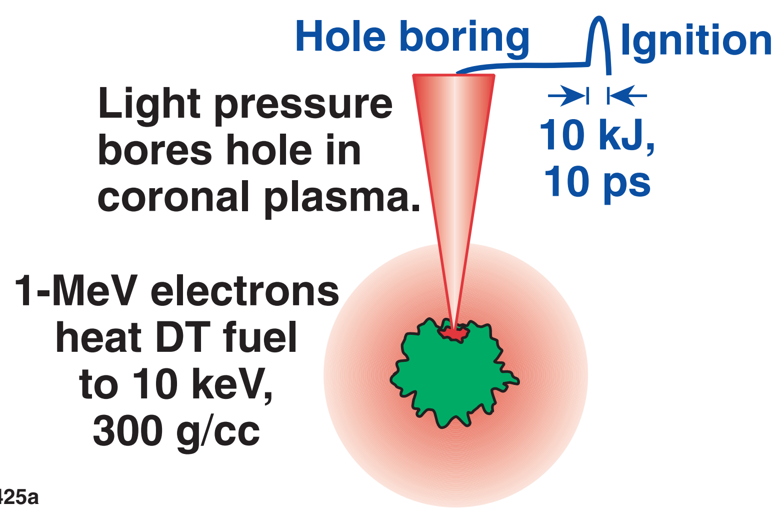
G5819b

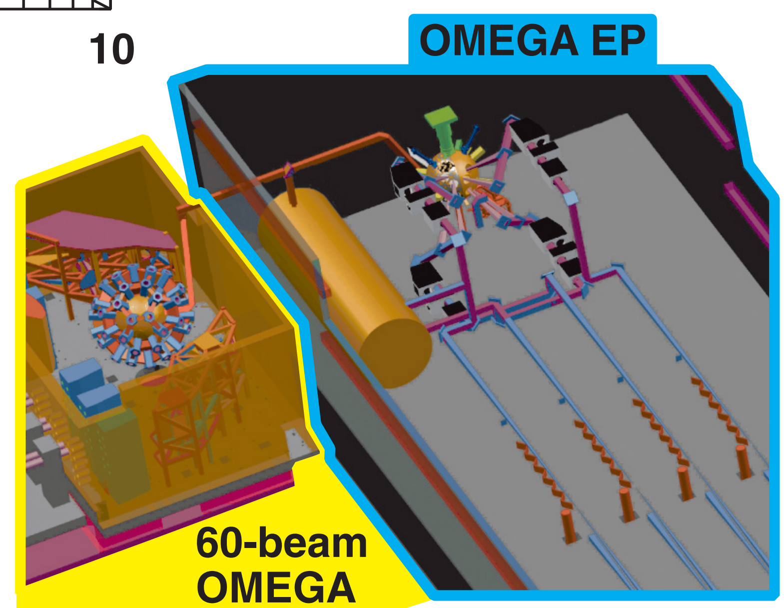
OMEGA EP will perform integrated cryogenic fast ignition experiments



- HEPW designs underway at LLE, LLNL, and SNL.



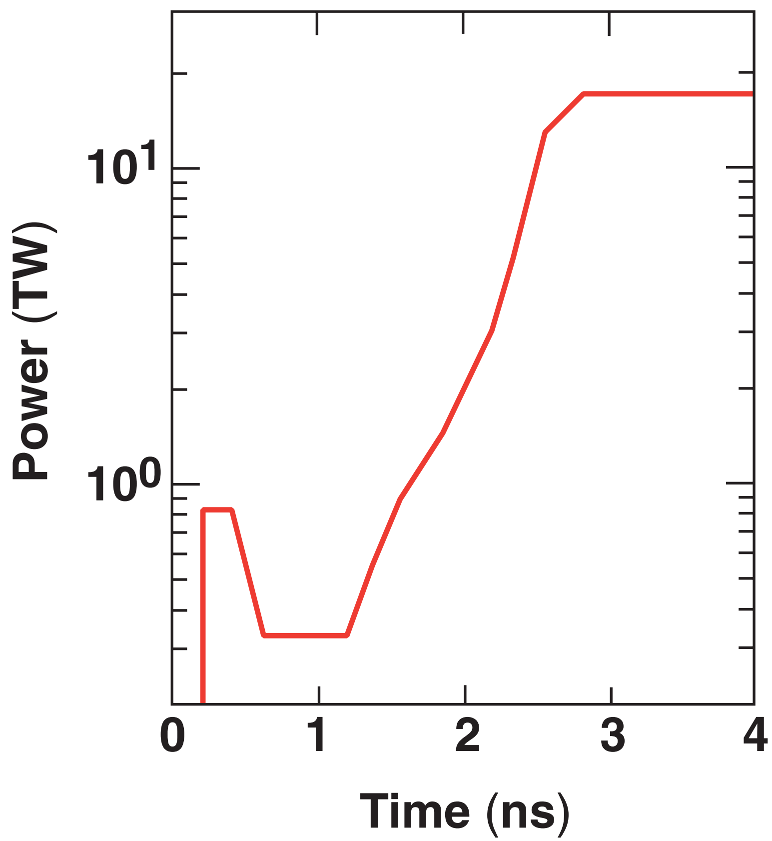


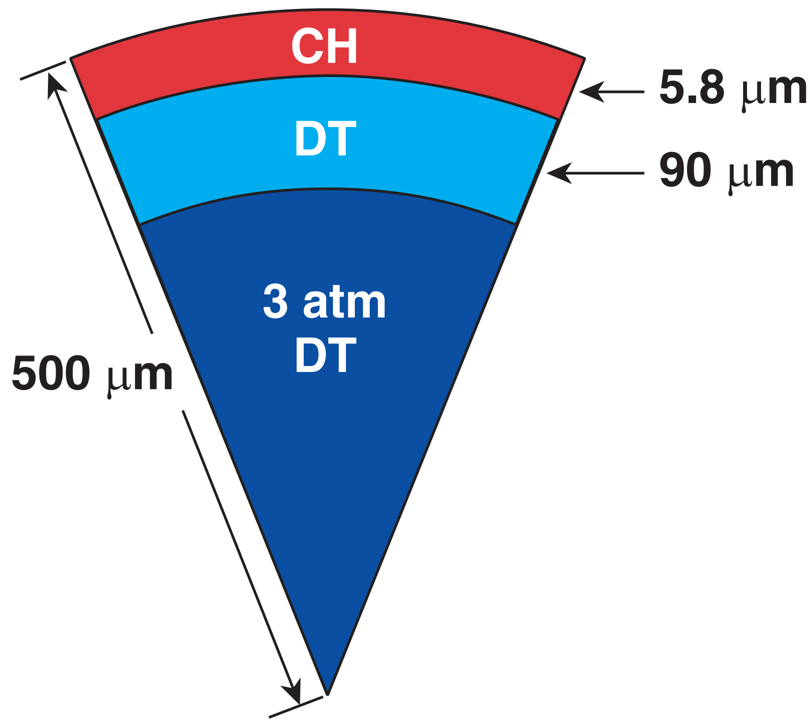


Under construction

I1425a

An OMEGA direct-drive cryogenic target is designed to give a density > 300 g/cm^3



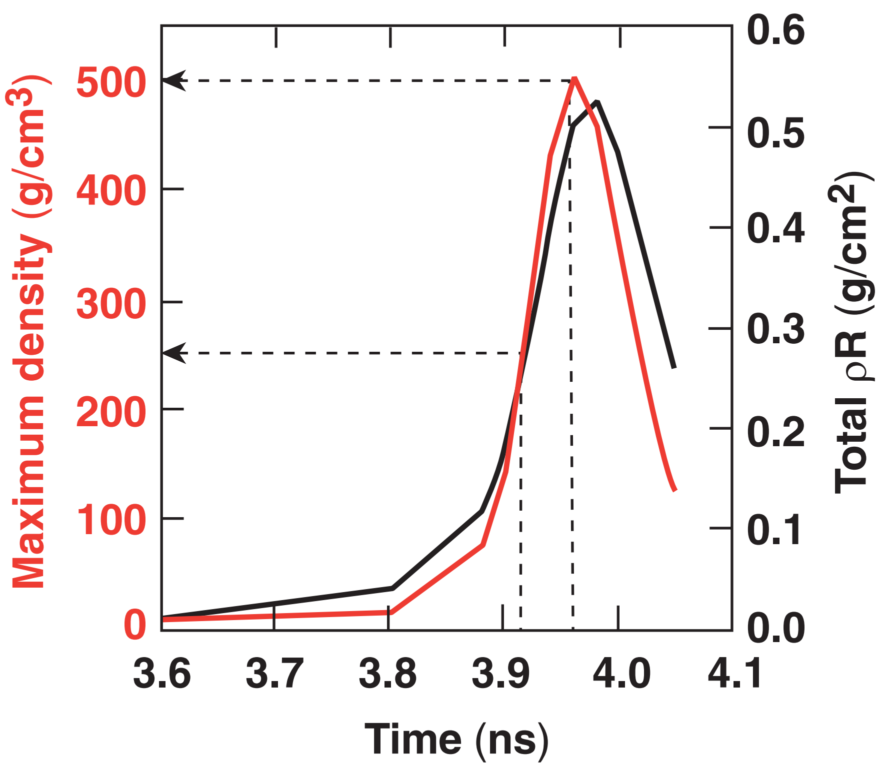


Nearly identical to capsules being imploded now.

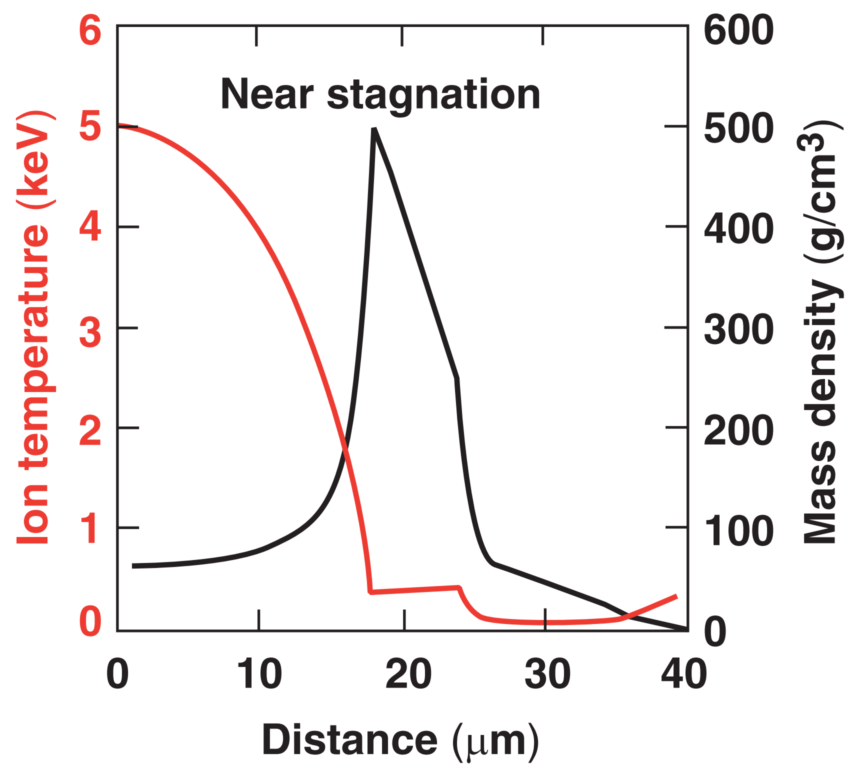
TC6195a

The areal density achieved with an OMEGA cryogenic target is close to ignition conditions

UR LLE



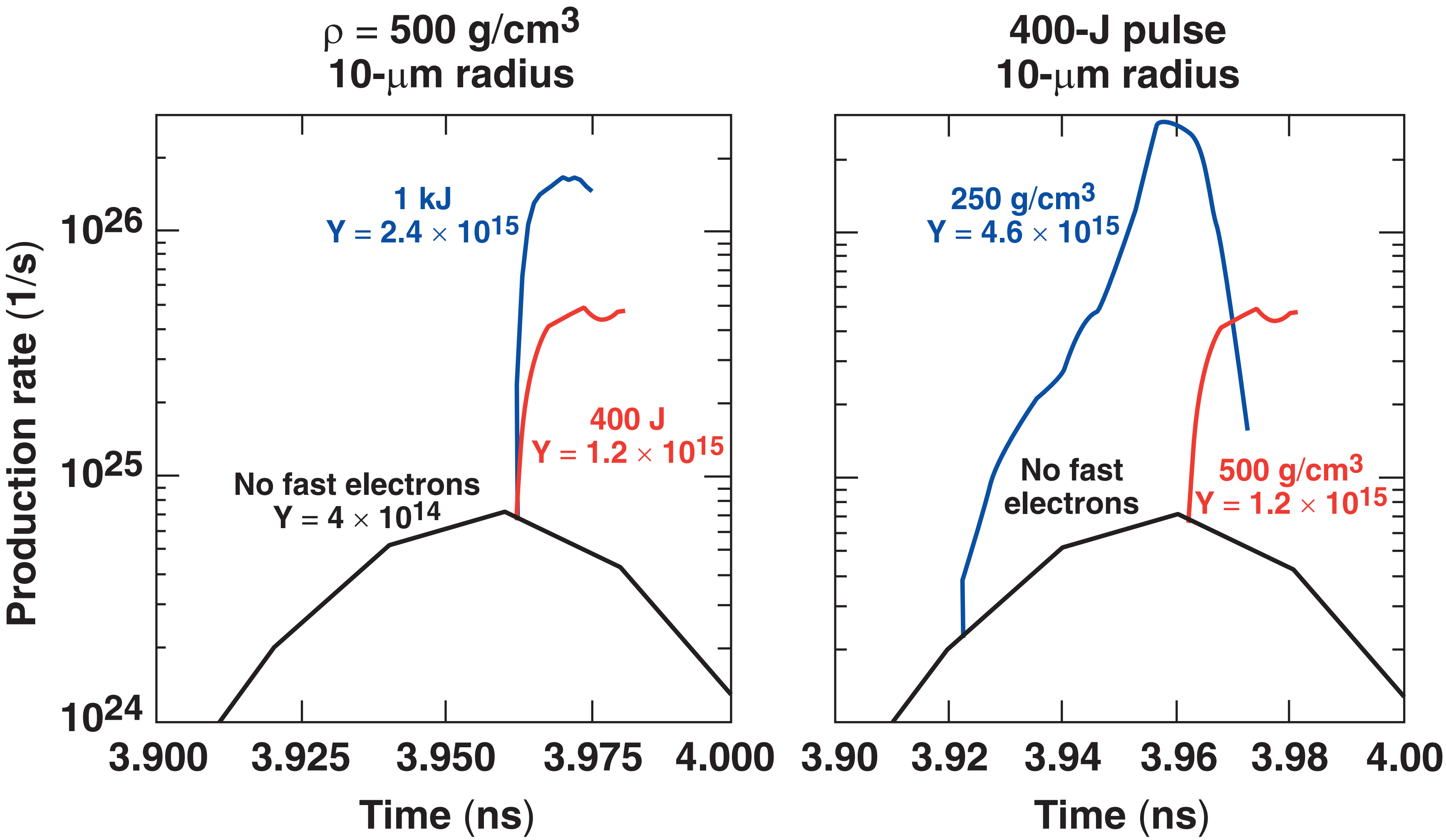
Ion temperature is well below ignition requirements



A 1-MeV electron has a range of about 0.4 g/cm^2.

TC6196a

The fast-ignitor beam creates a burst of neutrons that can be used for diagnostic development



TC6200a

Summary/Conclusions

LLE is making significant progress in direct-drive inertial confinement fusion research

UR LLE

- Adiabat-shaping techniques will allow
  - lower-adiabat (higher-compression) implosions on OMEGA and
  - higher-gain target designs for the NIF.
- Cryogenic target experiments are showing promise.
  - Ice-surface roughnesses are approaching 1 μm rms, ignition specifications.
  - The first wetted-foam target has produced the highest cryogenic D_2 neutron yield.
  - 2-D simulations are in good agreement with experimental observations.
- OMEGA EP (two ps beams, 2.6 kJ each) will extend LLE's research, including integrated fast-ignition experiments.

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