APPENDIX D

DIRECT DRIVE TARGET DESIGN

BY

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Direct Drive Target Design

Presented by Jill Dahlburg

Code 6736, Naval Research Laboratory

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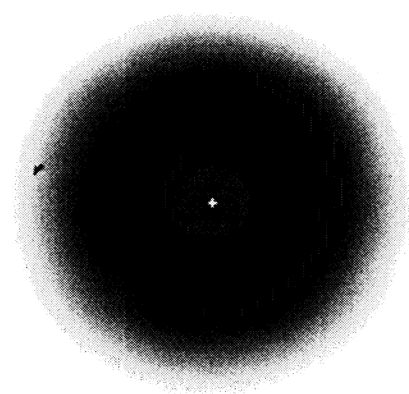
Lee Phillips (LCP&FD, NRL), Marcel Klapisch (ARTEP), Giora Hazak (BRA), Avi Bar-Shalom (SAIC),
Keith Obenschain (BRA), Rob Scott (LCP&FD, NRL), Stephen Obenschain (PPD, NRL), John Sethian (PPD, NRL),
Carl Pawley (PPD, NRL), Andrew Mostovych (PPD, NRL), Victor Serlin (PPD, NRL), Yefim Aglitskiy (SAIC)
& the Nike crew.



Outline ~

- Critical issues for direct drive Inertial Confinement Fusion [ICF] pellet design:
  design criteria in five areas

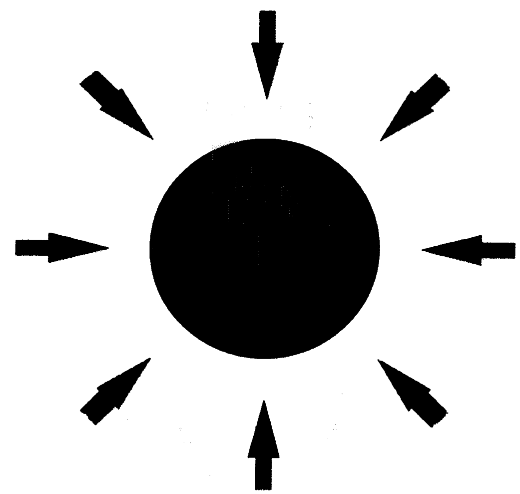
- Background:
  - Code
  - Experiment

- Target designs and specifications

There are five critical science issues in the design of a high gain pellet.

(1) Demonstration of sufficient coupling of the laser energy into the target;

(2) Keeping the fuel on a sufficiently low adiabat;



(3) Demonstrating sufficient implosion symmetry;

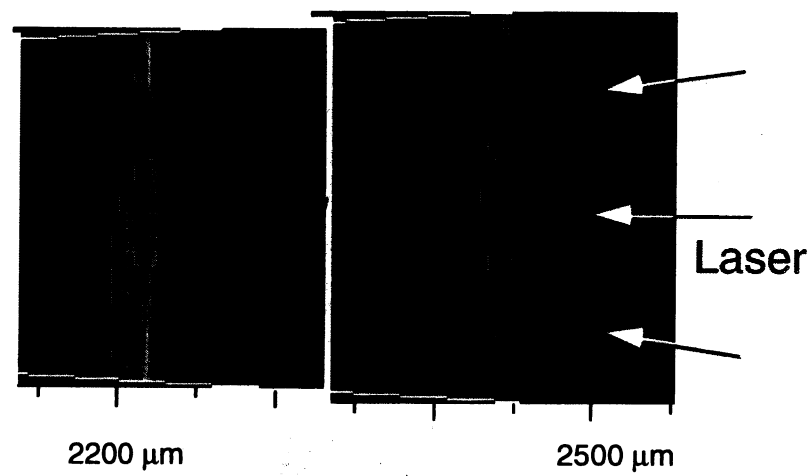
(4) Demonstrating sufficient target stability;

(5) Getting a sufficiently large hot spot to achieve ignition and propagating burn.

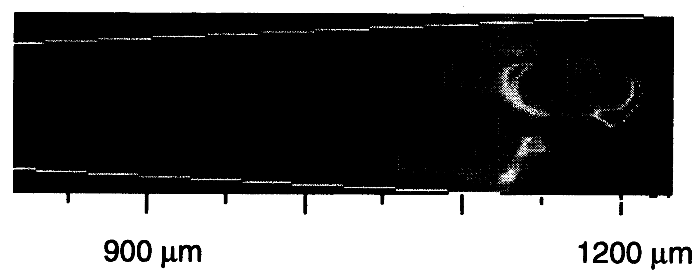
(4) Sufficient control of ablative RT.

Issues

- RT is seeded by imprint (from laser) and pellet mass imperfections.



- The perturbations can grow to destroy the pellet fuel before it implodes sufficiently to ignite and burn.



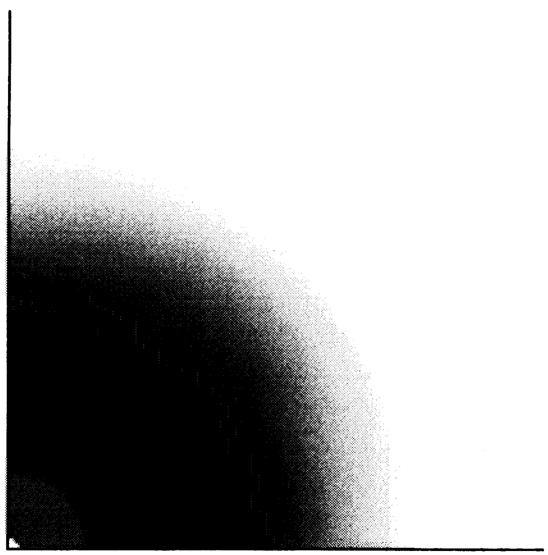
J.Gardner, FAST; 1998

NRL: VG 29 (7/23/99)

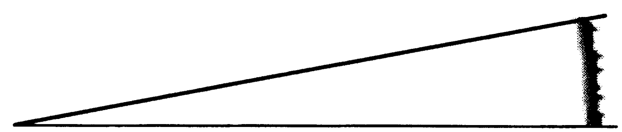
FAST employs sliding zone FCT to model nonlinear evolution of the Rayleigh-Taylor instability.

Code includes –
- Sliding zone Eulerian FCT advection
- Implicit solution of Spitzer thermal conduction
- Ray trace inverse bremsstrahlung ISI laser deposition
- Multigroup radiation transport with STA opacities
- Ray trace or diffusion alpha transport for thermonuclear burn

Geometry: ***r, θ***
Resolution: ***300 x 256***
BCs: reflecting or periodic in ***θ,***
and outflow at ***rmax***



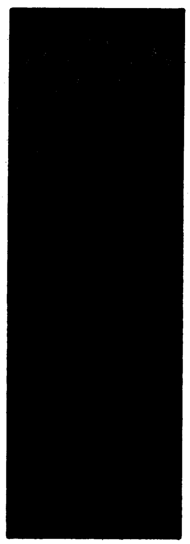
Low modes: $2 \leq l \leq 32$

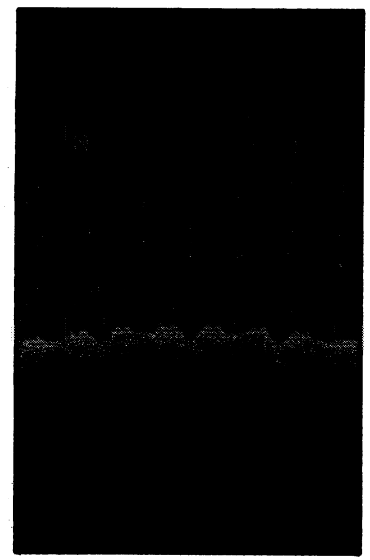


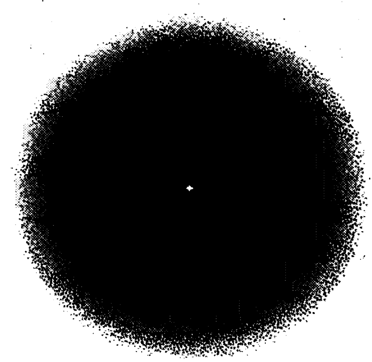
Moderate modes: $32 \leq l \leq 512$

Success of high-gain, high aspect-ratio pellets depends on Rayleigh-Taylor stabilization.

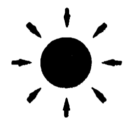
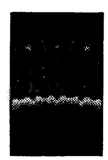
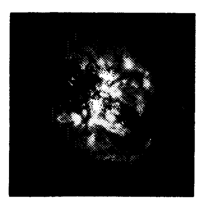
Short wavelengths saturate but lead to mix on the outer surface	Moderate wavelengths distort target and can lead to shell breakup	Long wavelengths distort target and can lead to core mix
$l \geq 512$	$16 \leq l \leq 512$	$l \leq 16$







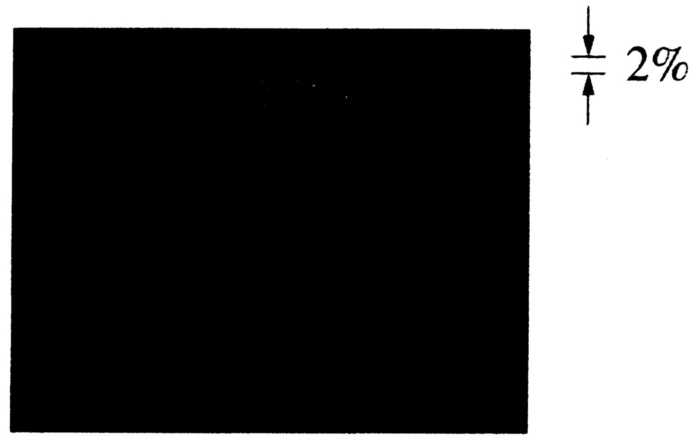
$1000\ \mu m \leq \lambda \leq 20\ \mu m$

Need experiments to address	Required laser system attributes
(1) Laser-target coupling 	Planar: *i)* long scale length *ii)* high I
(2) Target isentrope 	Planar: *i)* large, flat spot *ii)* pulse shaping
(3) Low-mode symmetry 	Spherical: *i)* beam balance *ii)* pulse shaping
(4) Ablative Rayleigh-Taylor 	Planar: *i)* large, flat spot *ii)* uniform drive beam *iii)* pulse shaping
(5) Ignition / burn 	Spherical: *i)* uniform illumination (beam-to-beam and single beam) *ii)* large energy

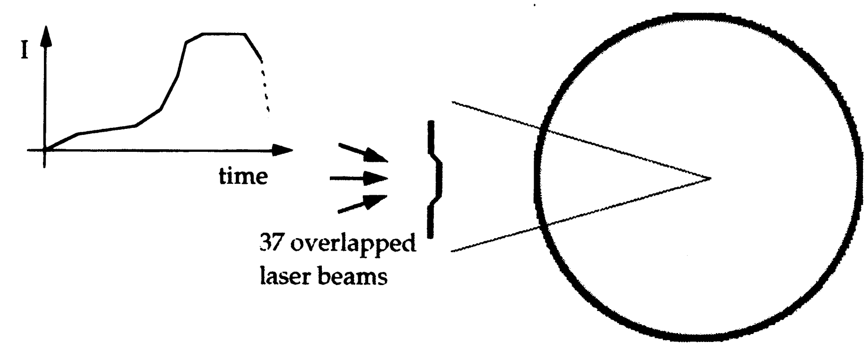
NRL: VG14 (7/23/99)

Nike KrF laser facility parameters and specifications:

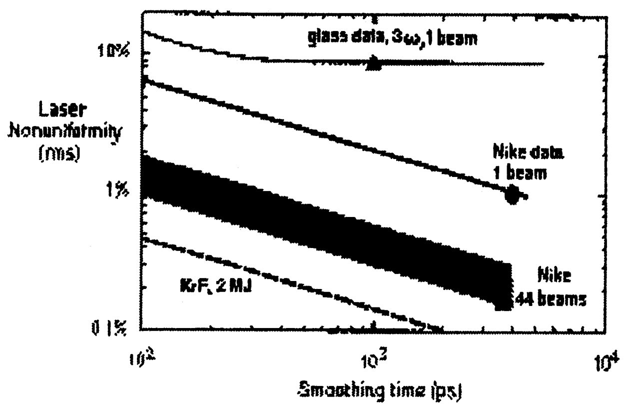
Whole beam planarity with beam overlap:



Pulse shaping:



Beam speckle smoothing:



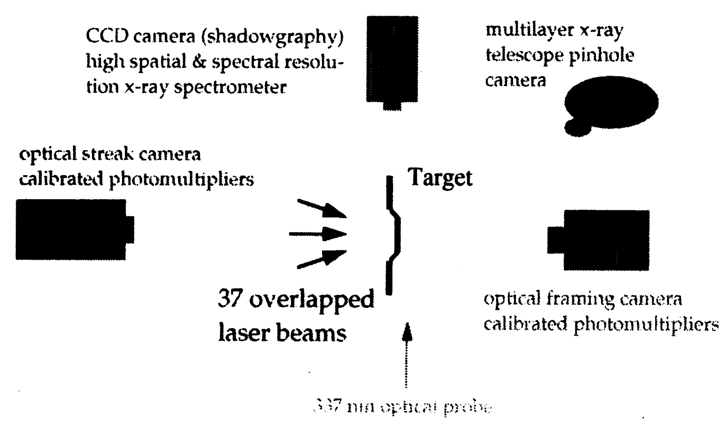
10% @ 0.3 THz

← 1 THz ISI

0.2% @ 1.0 THz
(+ beam overlap)

Bandwidth can be dialed from 0.3 to 3.0 THz

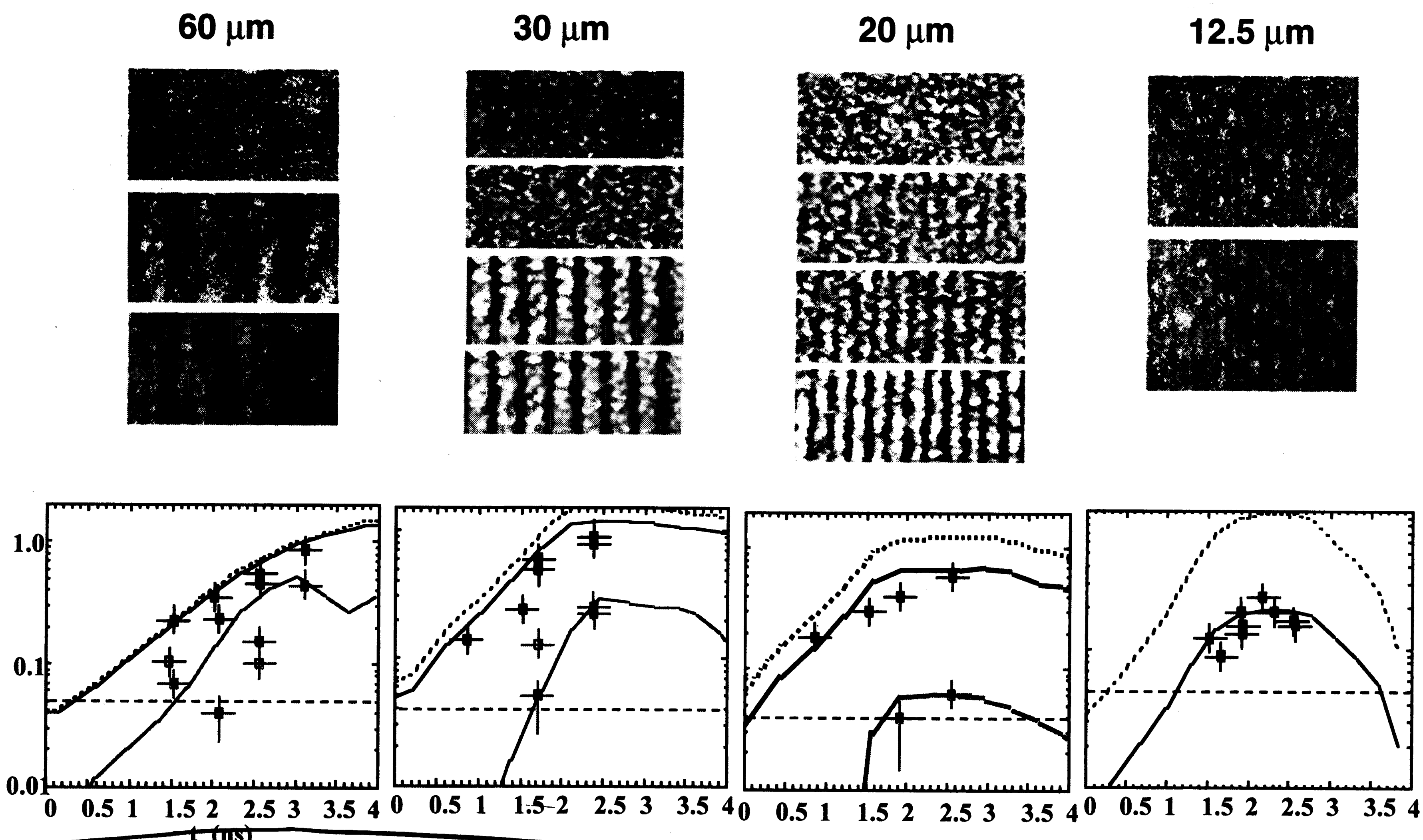
Diagnostic suite:



NRL: VG 13 (7/23/99)

Nike experiments with sinusoidal modulations agree well with NRL's 2D rad/hydro code.

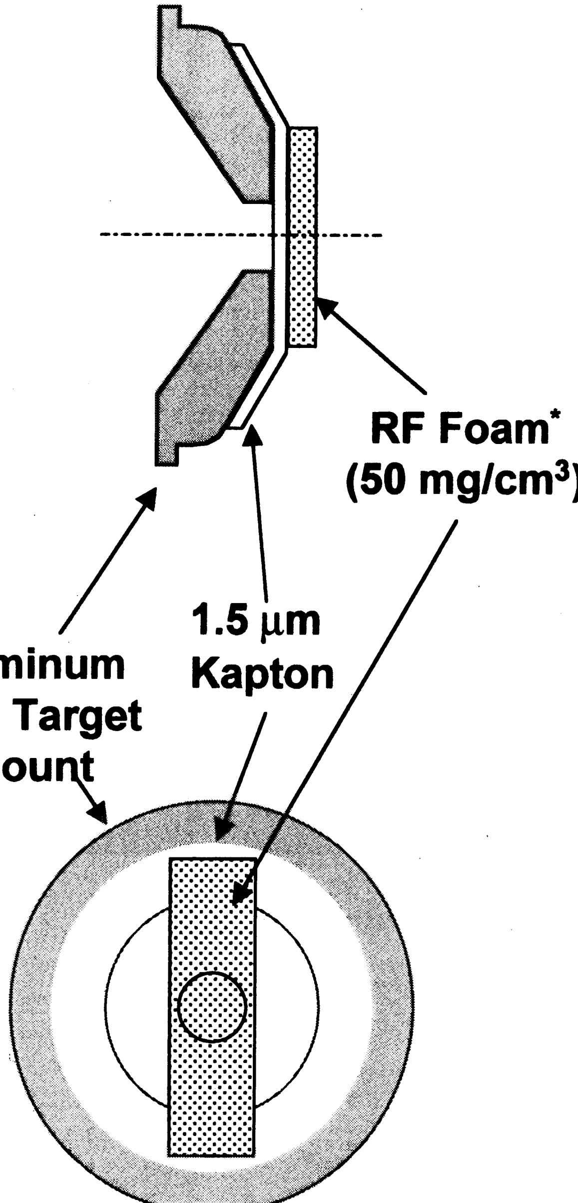
NRL

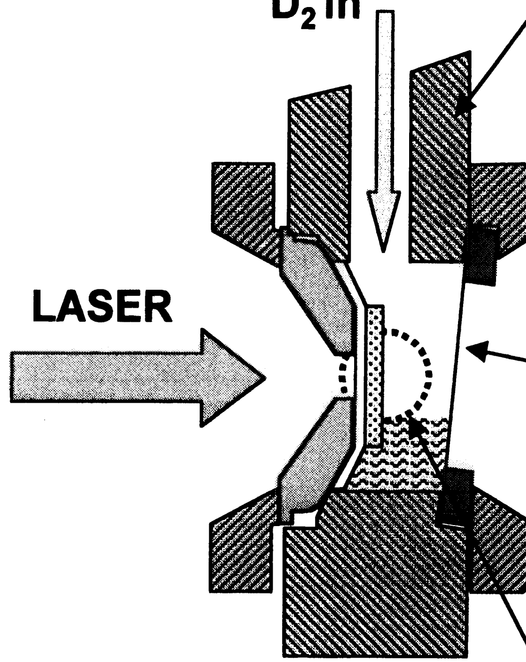


CH (perturbed) targets

NRL: VG 31 (7/23/99)

Nike Cryo targets are liquid D_2 wicked into a low density foam, with a Kapton overcoat





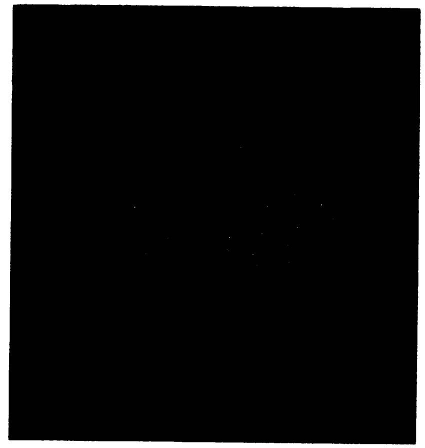
* Resorcinol Formaldehyde (RF) Foam:
42% C, 17% O, 41% H (atomic %)
0.1 μm pore size, 150 Å fiber dia

Imprint on foam + D_2

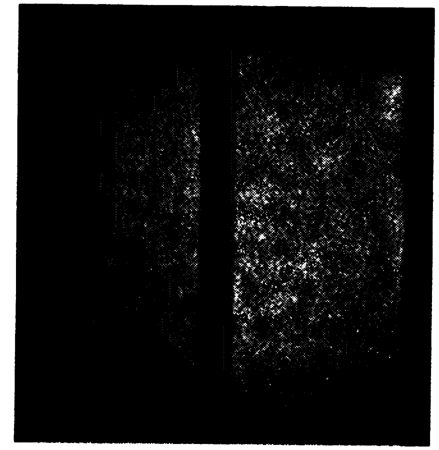
NRL: VG 33 (7/23/99)

With a smooth foot the mass modulations appear later and do not grow as much

Multi-beam foot (~0.2% non uniformity in foot)

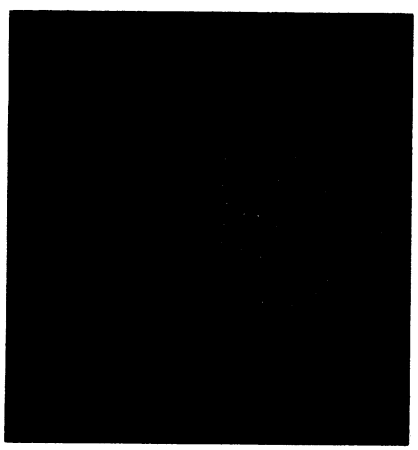


0.8 ns 1.4 ns

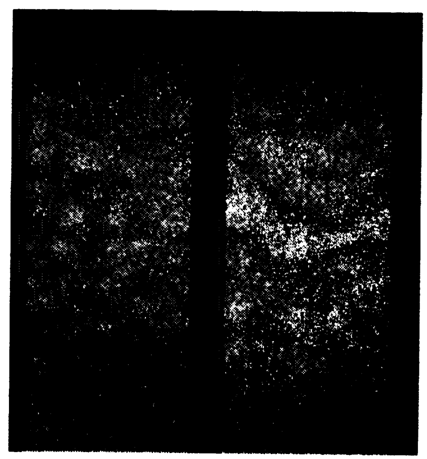


2.4 ns 3.0 ns

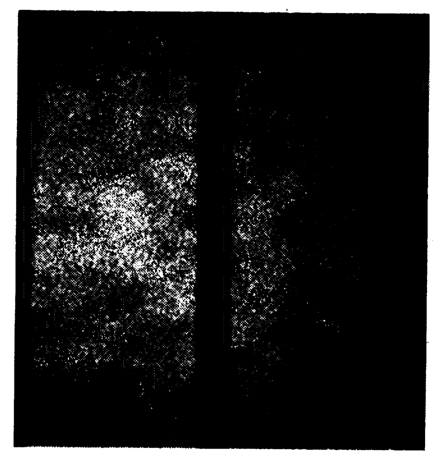
Single-beam foot (~1.2% non uniformity in foot)



0.0 ns 0.6 ns



1.3 ns 1.9 ns

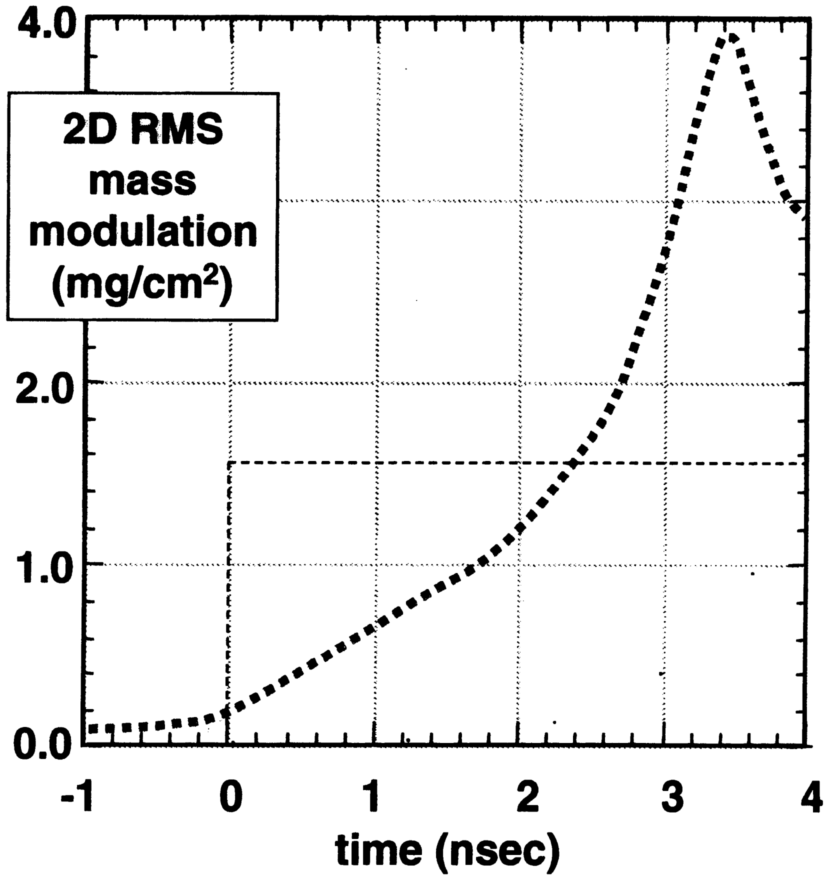


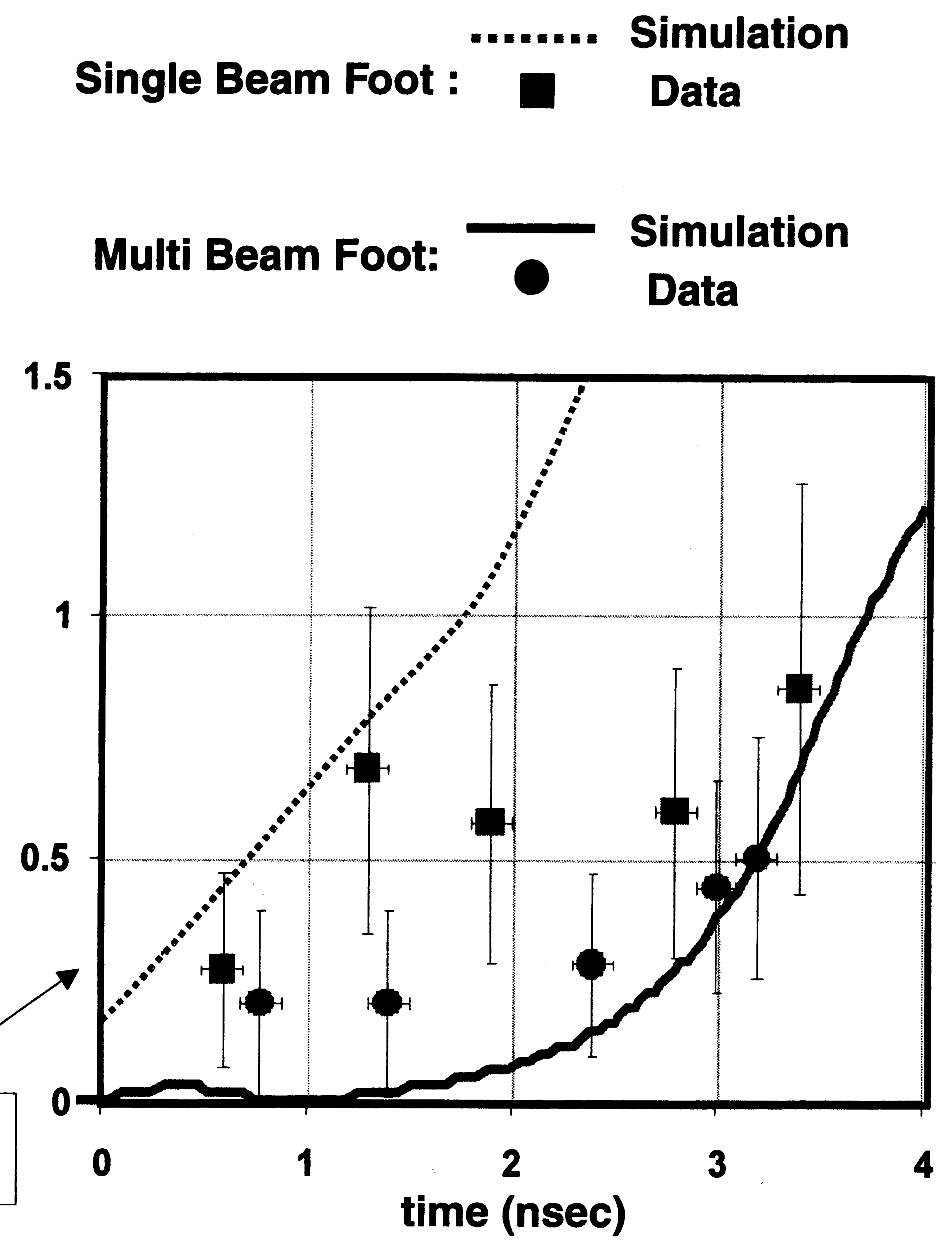
2.8 ns 3.4 ns

Imprint on foam + D_2

NRL: VG 34 (7/23/99)

Comparison of data and FAST 2D predictions of areal mass modulations





Error bars due to uncertainties in analyzing images
Nominal ~~units of vertical~~ axis are mg/cm²

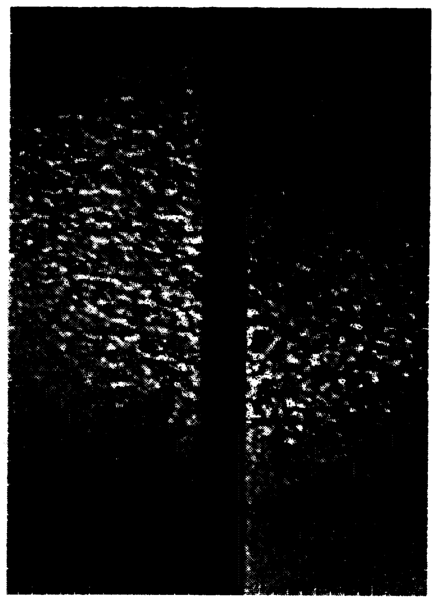
Imprint on foam + D_2

NRL: VG 35 (7/23/99)

Useful **planar** RT experiments require less uniformity than implosions

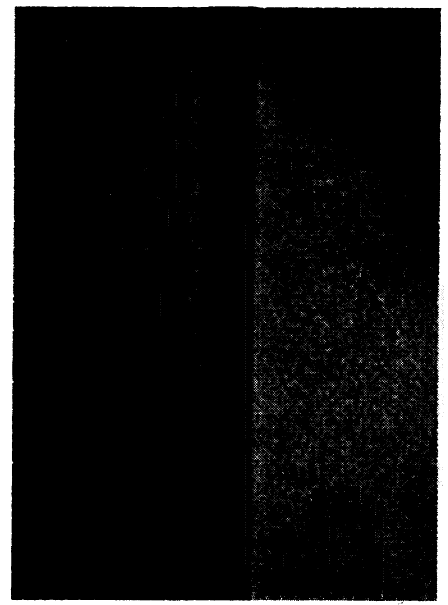
Nike **single beam** imprint on CH target with and without thin Au layer

No Au



0.9 ns 1.5 ns

With Au



0.8 ns 1.7 ns

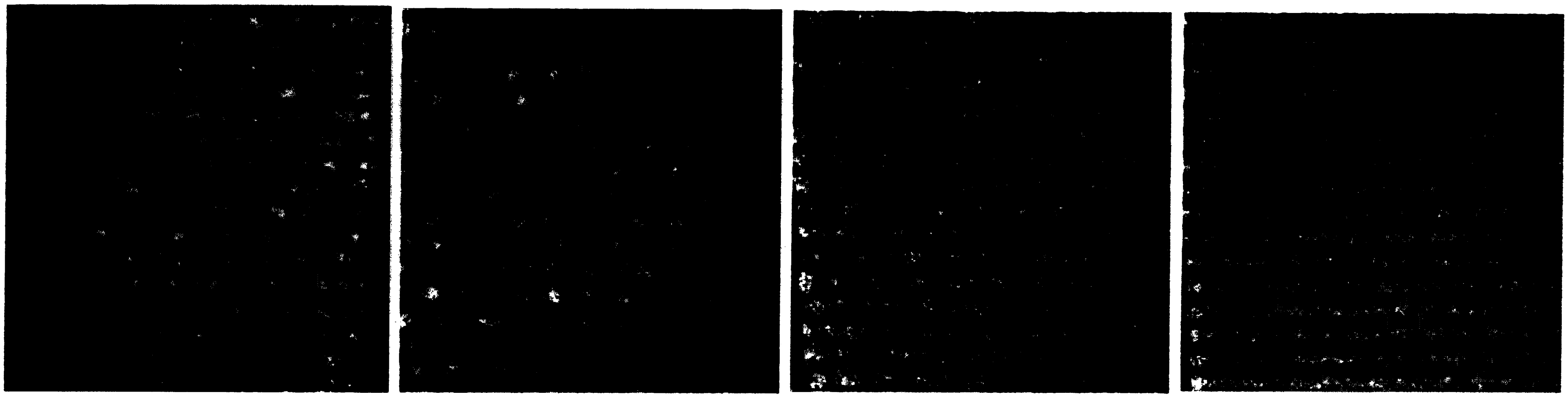
Overlapping 8 beams in NIF planar improves effective uniformity 2.8x

Imprint mitigation with CH+ Au layers

[NRL: VG 36] (7.23.99)

Images for each gold layer case where the amplitude of the 20 μm sine wave is near .8 mg/cm^2.

no gold | 100 Angs. gold | 200 Angs. gold | 400 Angs. gold



For a constant amount of R-T growth at $\lambda = 20$ um, the “imprint” is worst at 100 Angstroms of gold.

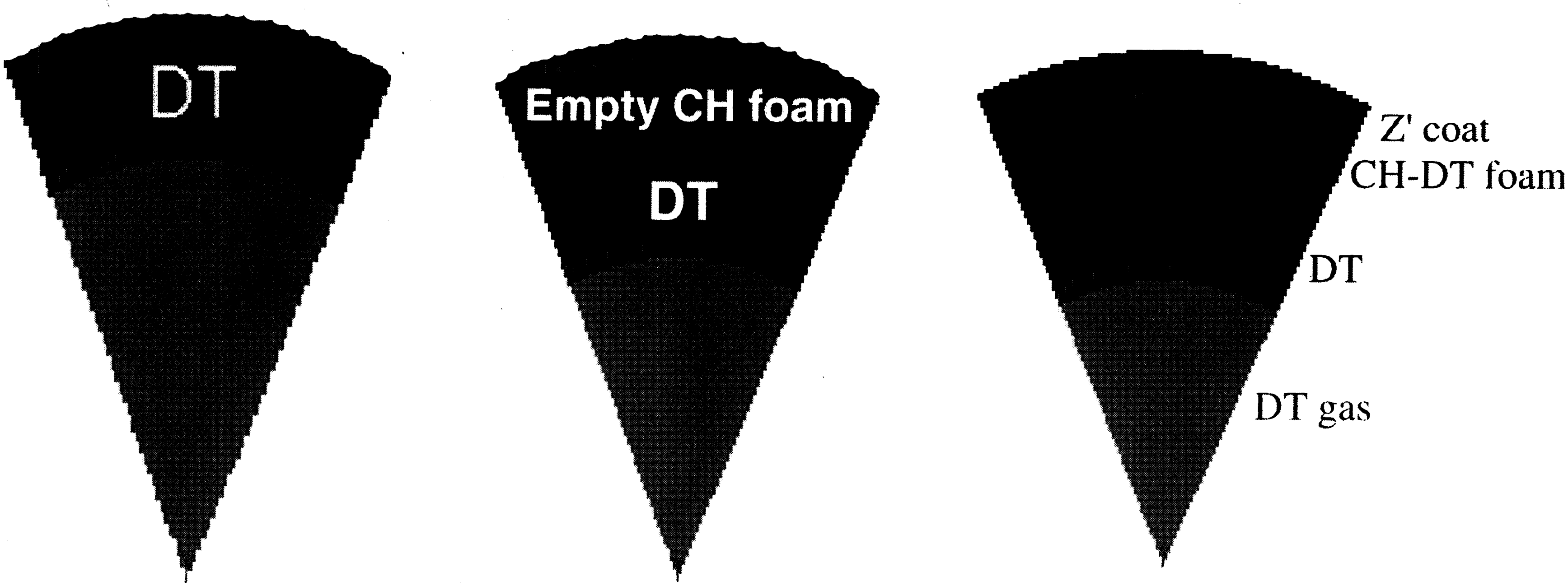
Imprint mitigation with CH + Au layers

NRL: VG 37 (7.23.99)

(4) Engineer a tailored adiabat:

- RT stable at ablation (high-adiabat),
- with inner fuel cold for ignition (low-adiabat).

Pellet Concepts

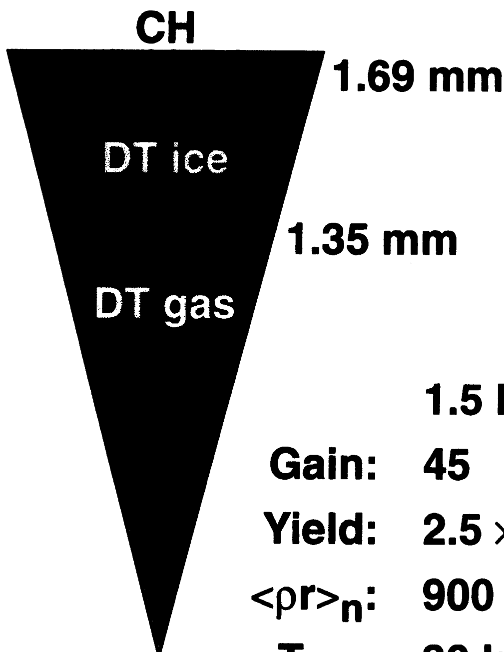


... Shock Heating ... Radiation Preheat

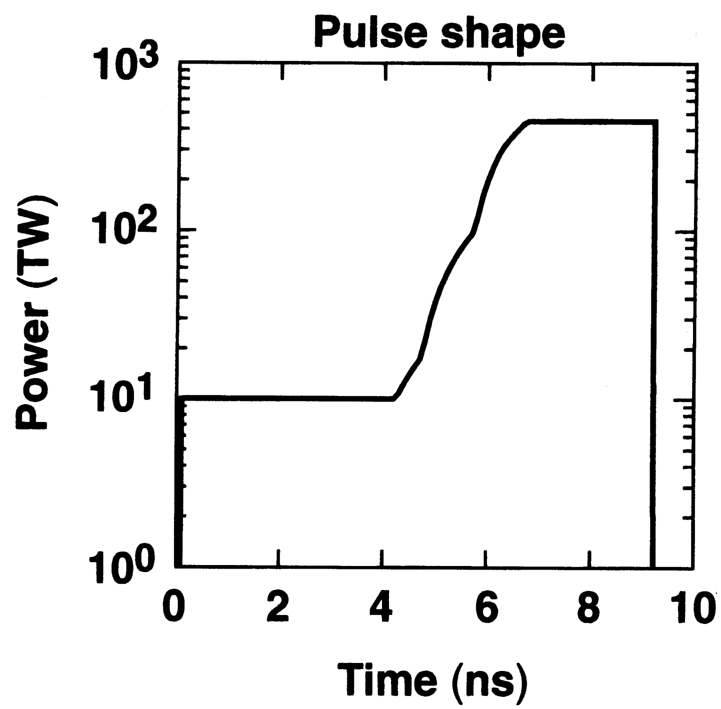
NRL: VG 38 (7/23/99)

The "all-DT" direct-drive target is a thick DT-ice layer enclosed by a thin CH shell

UR LLE



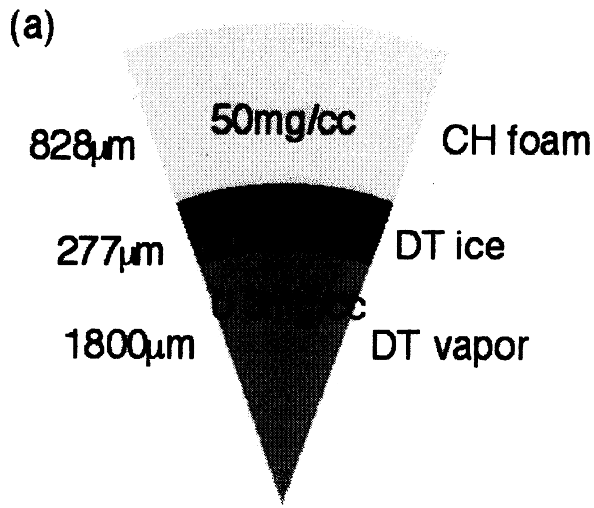
	1.5 MJ, $\alpha = 3$
Gain:	45
Yield:	2.5×10^{19}
$\langle \rho r \rangle_n$:	900 mg/cm^2
$\langle T_i \rangle_n$:	30 keV
Hot spot CR:	29
Peak IFAR:	60

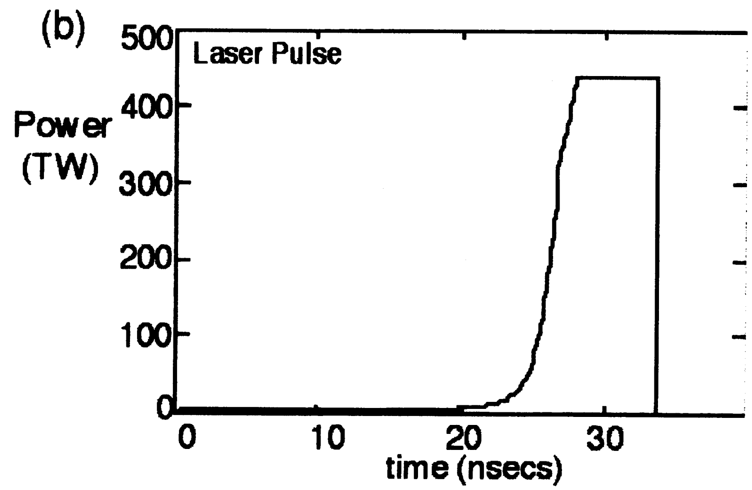


TC5080

VG 39

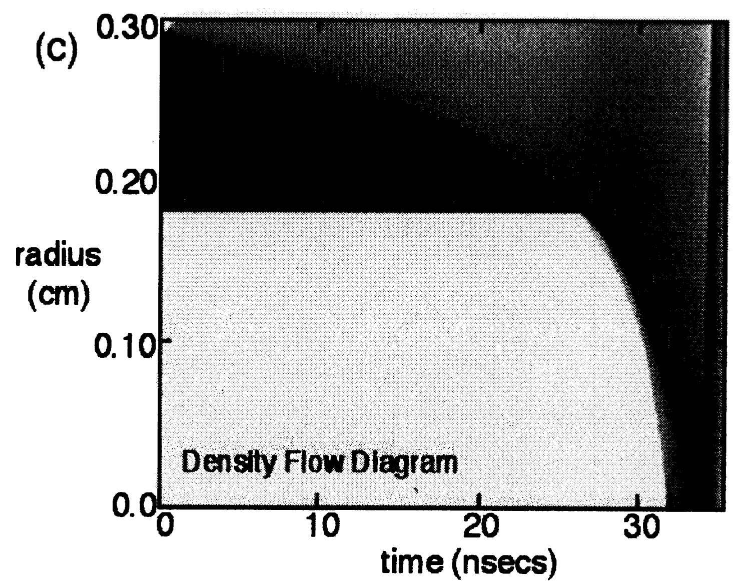
The "low-density foam" design is comprised of an imprint- and RT-resistant low-density CH foam ablator surrounding a DT shell.





CH Foam/DT Pellet Design

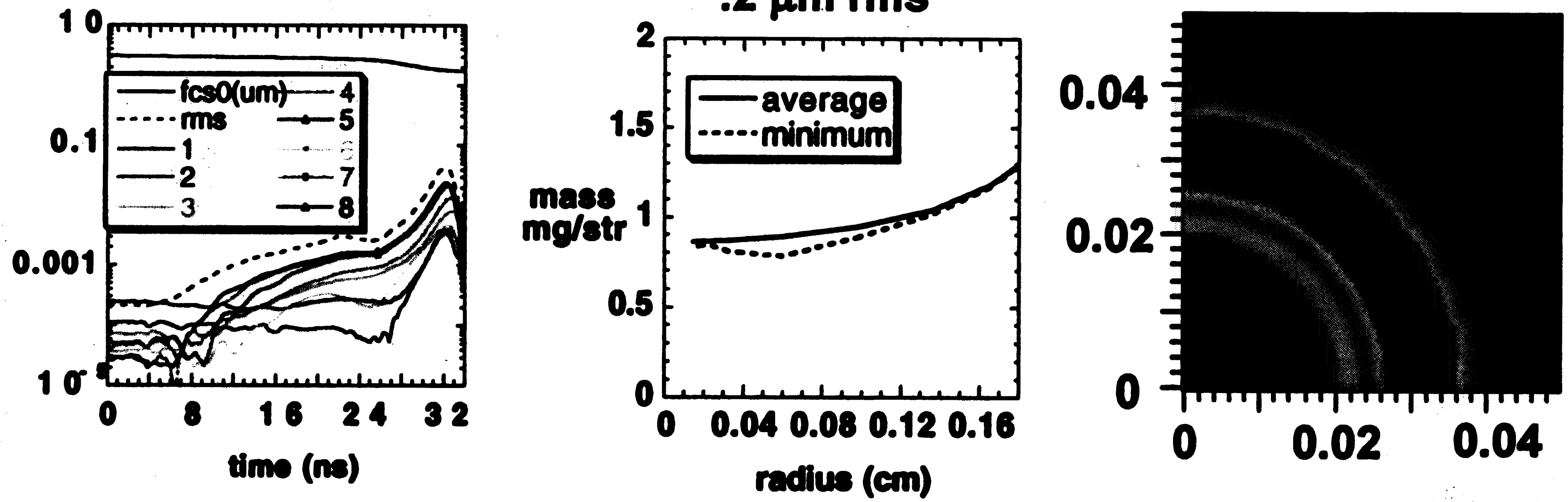
Laser Energy	3.4MJ
Laser Intensity	5×10^{14} W/cm^2
Laser Power (peak)	440 TW
Absorption fraction	0.87
Hydro Efficiency	8.5%
Implosion Velocity	3.2×10^{7} cm/s
Peak Fuel ρR	2.1 g/cm^2
IFAR	≤ 50
Gain	80



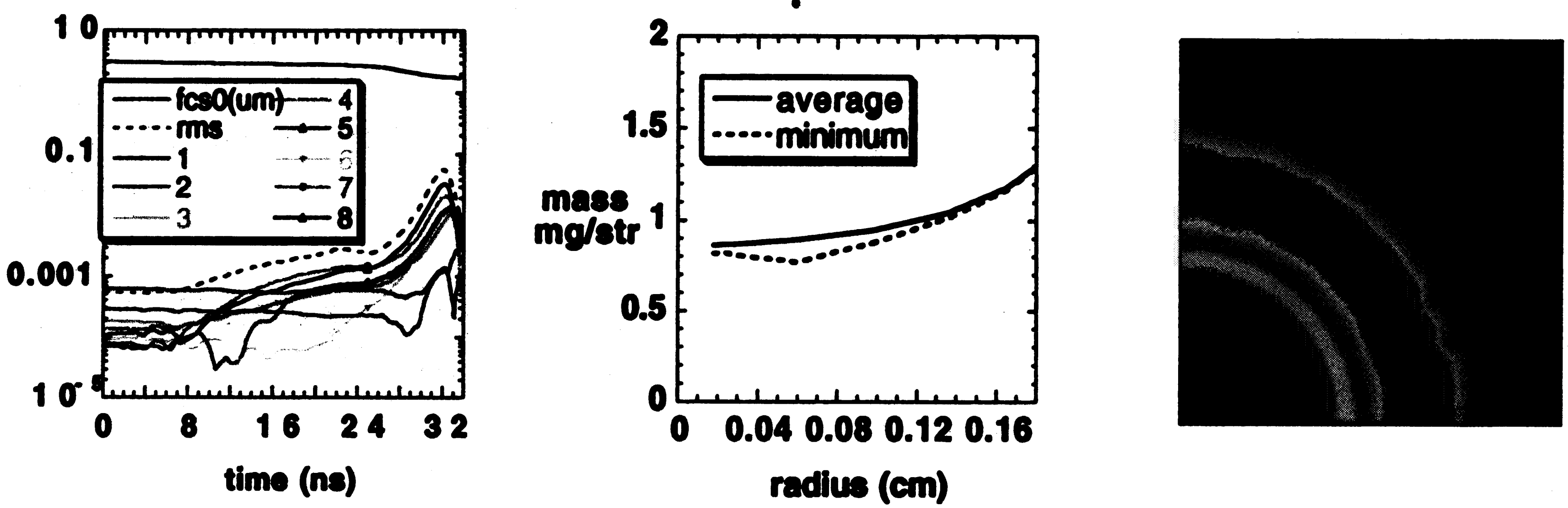
NRL: V640 (7.23.99)

Foam target is calculated to be reasonably stable to inner surface DT ice perturbations.

.2 µm rms

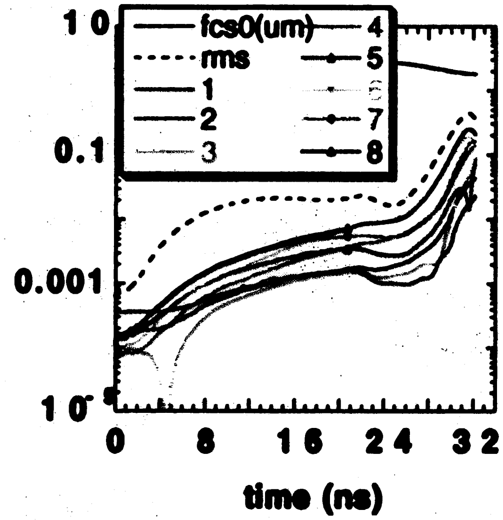


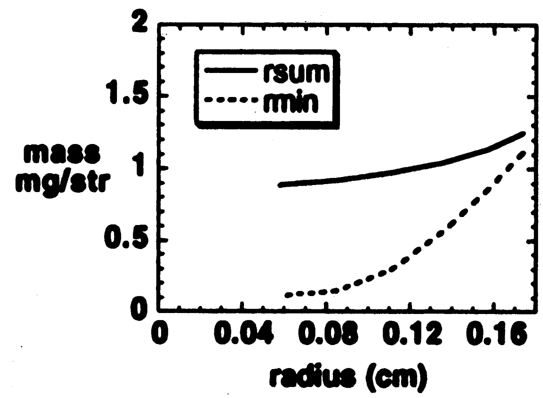
.5 µm rms

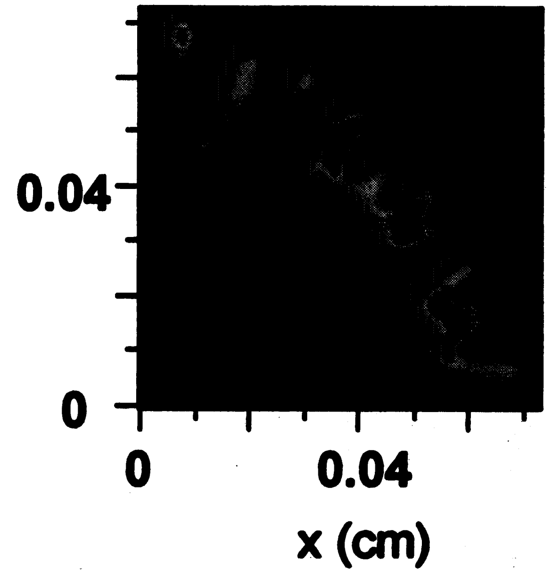


Comparison of outer surface roughness shows surface finish must be less than 500Å rms.

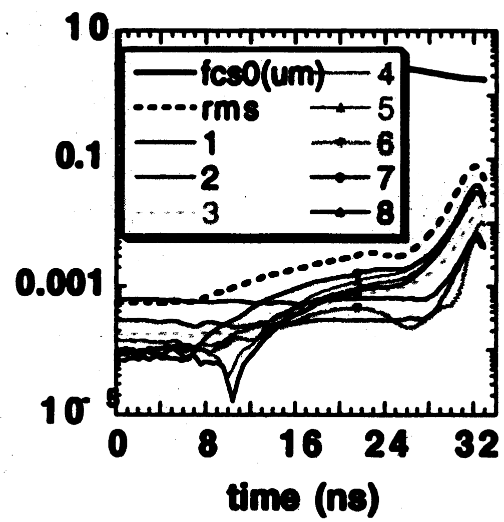
5000Å rms

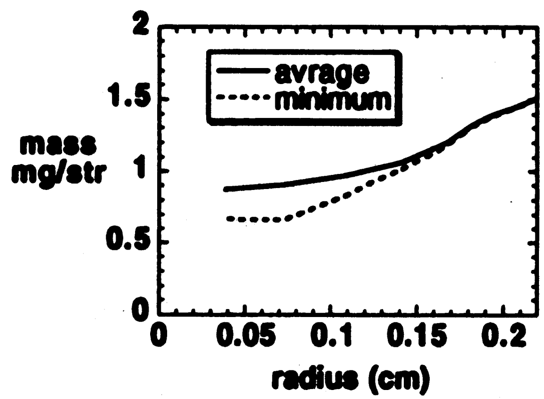


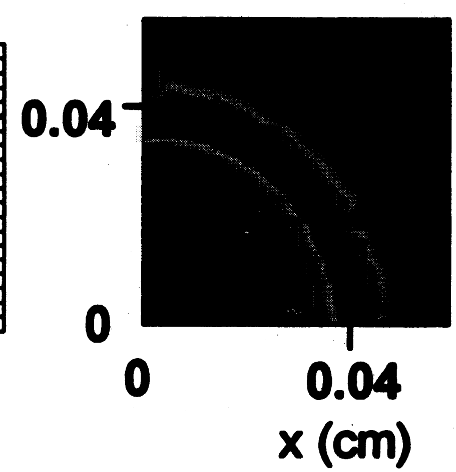




500Å rms

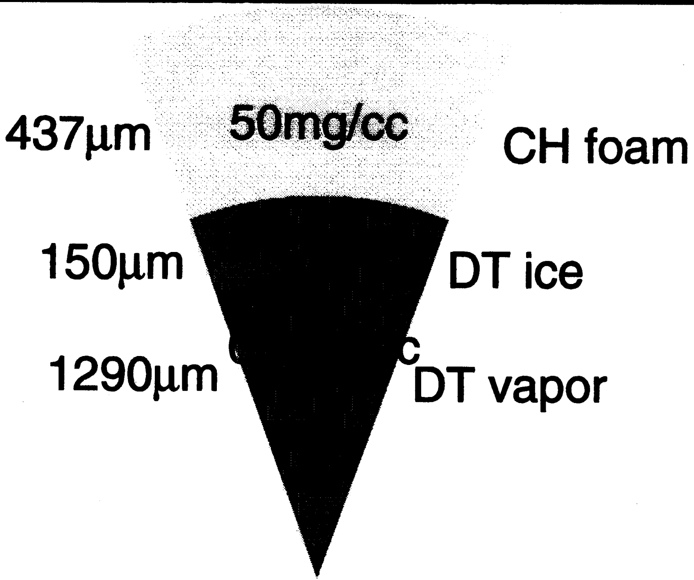


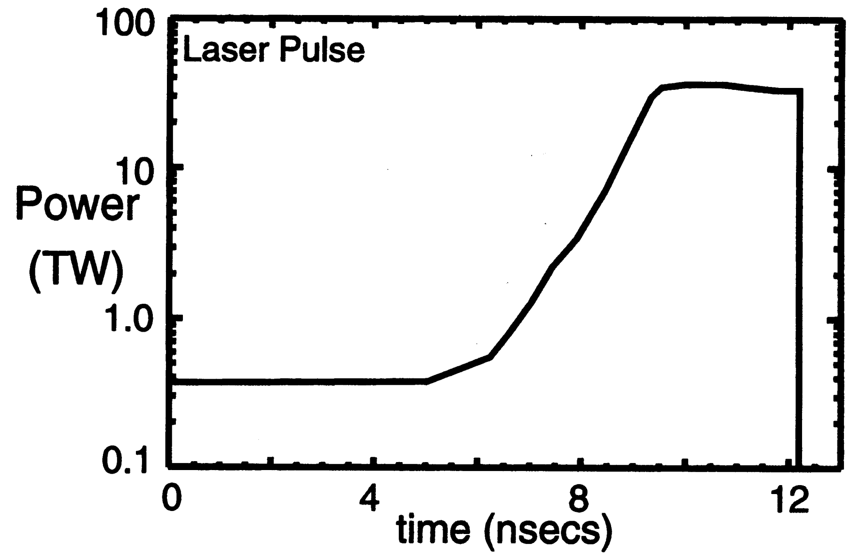




ICF RT 17

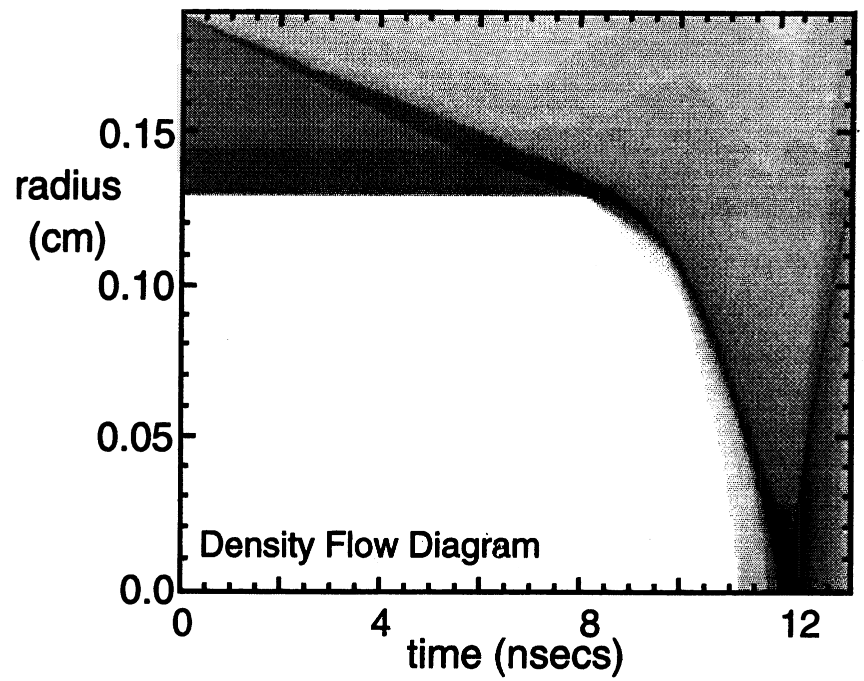
Foam ablator target for NIF





CH Foam/DT NIF target Design

Laser Energy	1.6MJ
Laser Intensity	9×10^{15}W/cm^2
Laser Power (peak)	37 TW
Absorption fraction	0.72
Hydro Efficiency	7.9%
Implosion Velocity	5×10^7cm/s
Peak Fuel ρR	0.8 g/cm^2
IFAR	~50
Gain	2



High target gain (>100) requires designs that preheat the ablator while keeping the DT fuel on low isentrope.

NRL high gain target design:

E_L ~ 1.2 MJ

Gain ~ 135
(*with laser zooming*)

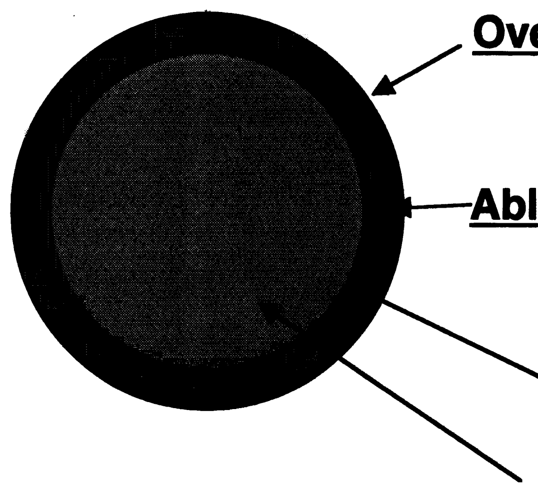
R_{spark} ~ 56 g/cc

R_{max} ~ 280 g/cc

$I_{max} = 7 \times 10^{14}$ W/cm^2

IFAR ~ 50

DMOT ~ 35

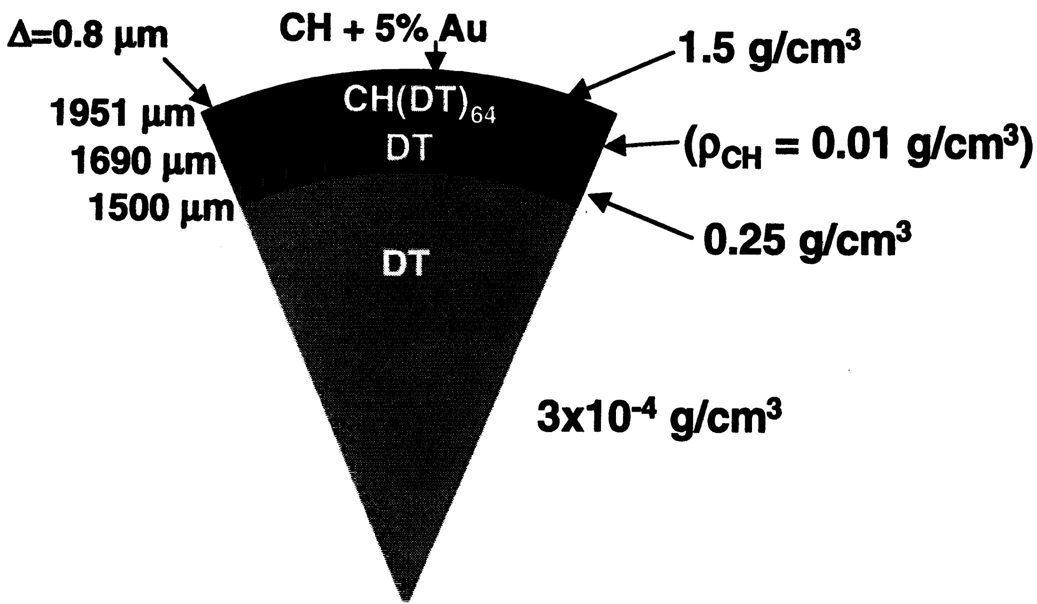


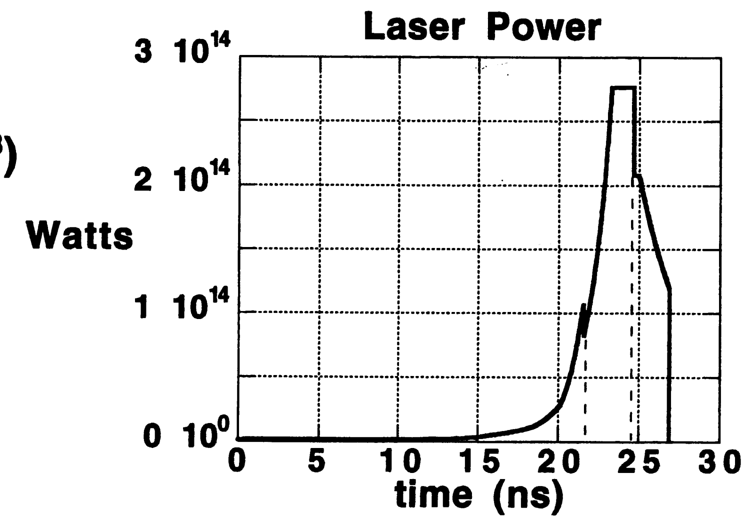
Fluid instabilities controlled by:

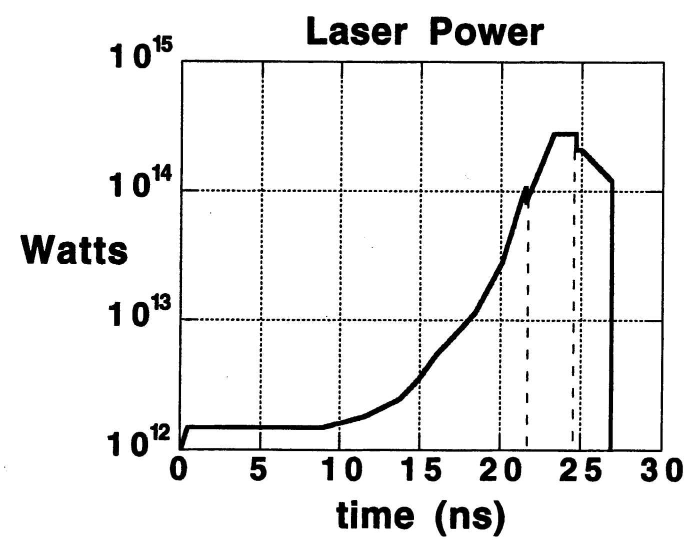
1. Preferential radiative heating of ablator by the high-Z overcoat and by the low-opacity foam
2. Reduced mass perturbations using ultra-uniform broadband laser beams.

Prototype target design for laser fusion energy.

NRL







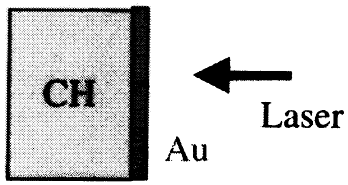
E_{Laser} = 1.2 MJ (with zooming)

1D Yield = 160 MJ

Gain = 135

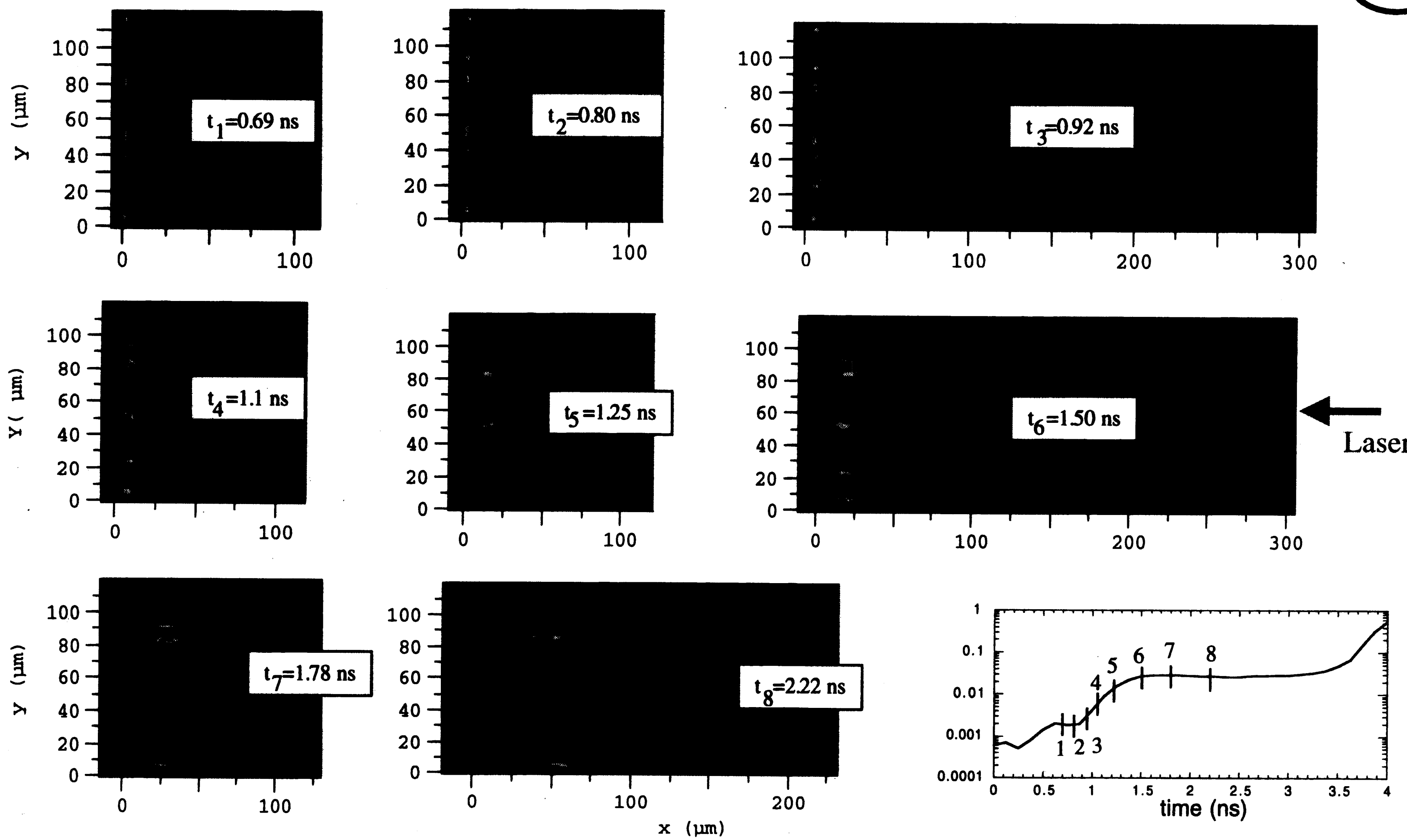
NRL: VG 42 (7.23.99)

Modeling a thin high Z overcoat layer provides several numerical challenges



High resolution is needed to model a thin expanding layer
The Au layer is Rayleigh-Taylor unstable; the layer needs to be followed accurately until mix is complete.

NRL



Summary ~ We are pursuing two types of tailored adiabat target designs:

– Foam targets (shock heated)

– Coated targets (radiation heated)

- Inner surface uniformity: ~ 0.5 μm RMS ice layer

- Outer surface uniformity: ~ 500 - 5000 Å RMS, for ignition
~ ≤ 500 Å for high gain

[The high gain specifications assume:
2 THz laser bandwidth with 0.249 μm light.]