Progress in high-gain directly driven target designs for energy

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U. S. Naval Research Laboratory

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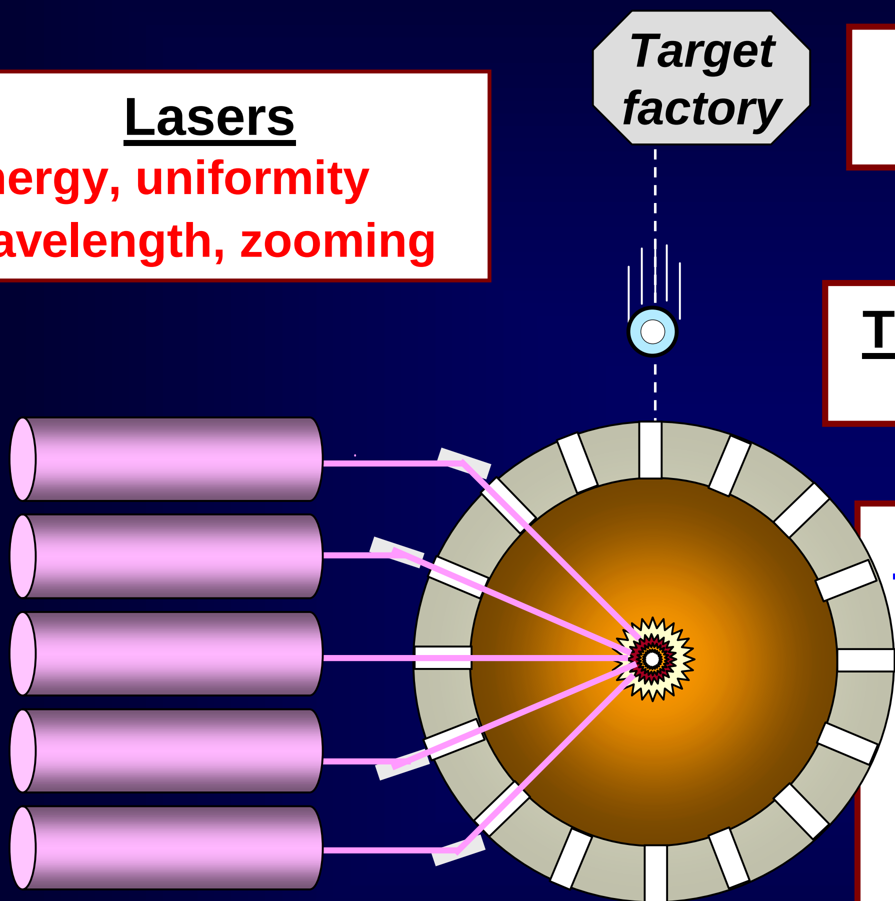
High-resolution integrated 2-dimensional simulations of pellet implosions with a shock-induced “tailored adiabat” predict high gains (~160) despite “realistic” target and laser imperfections.

Work by NRL laser fusion team with contributions from LLNL and LLE.

Pellet design affects many laser-fusion systems

Lasers
energy, uniformity
wavelength, zooming



Target Fabrication
surface finishes, materials & chemistry

Target Injection
foam insulation? lower temperature?

Laser pellet designs for energy

- Need gains >100
- Robust to laser & target imperfections
- Robust against unknowns in the implosion physics.
- Consistent with economics of power generation

Final Optics
F#, number of beam clusters

Chambers & Materials
target debris, x-ray output

Inertial fusion with laser illuminated deuterium-tritium (DT) fueled pellets

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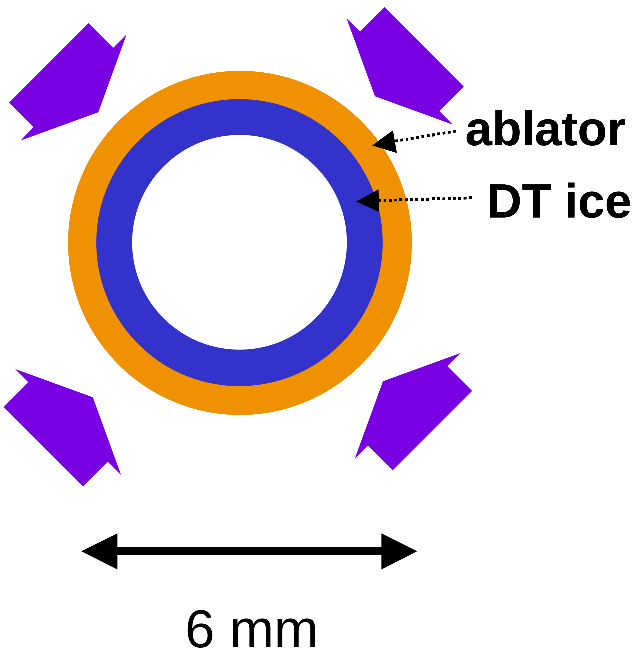
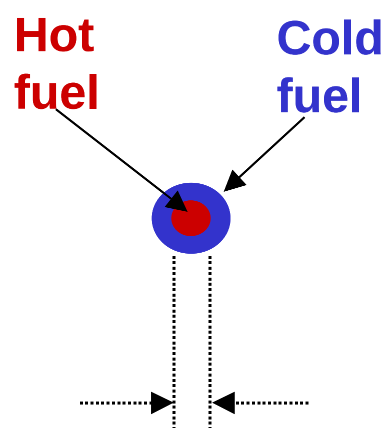
Lasers heat outside of pellet, imploding fuel to velocities of ~400 km/sec

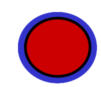


Central portion of DT (spark plug) heats to ignition.



~ 3% of original target size

Thermonuclear burn then propagates outward to the compressed DT fuel.



The primary physics concern for direct-drive laser fusion is hydrodynamic instability

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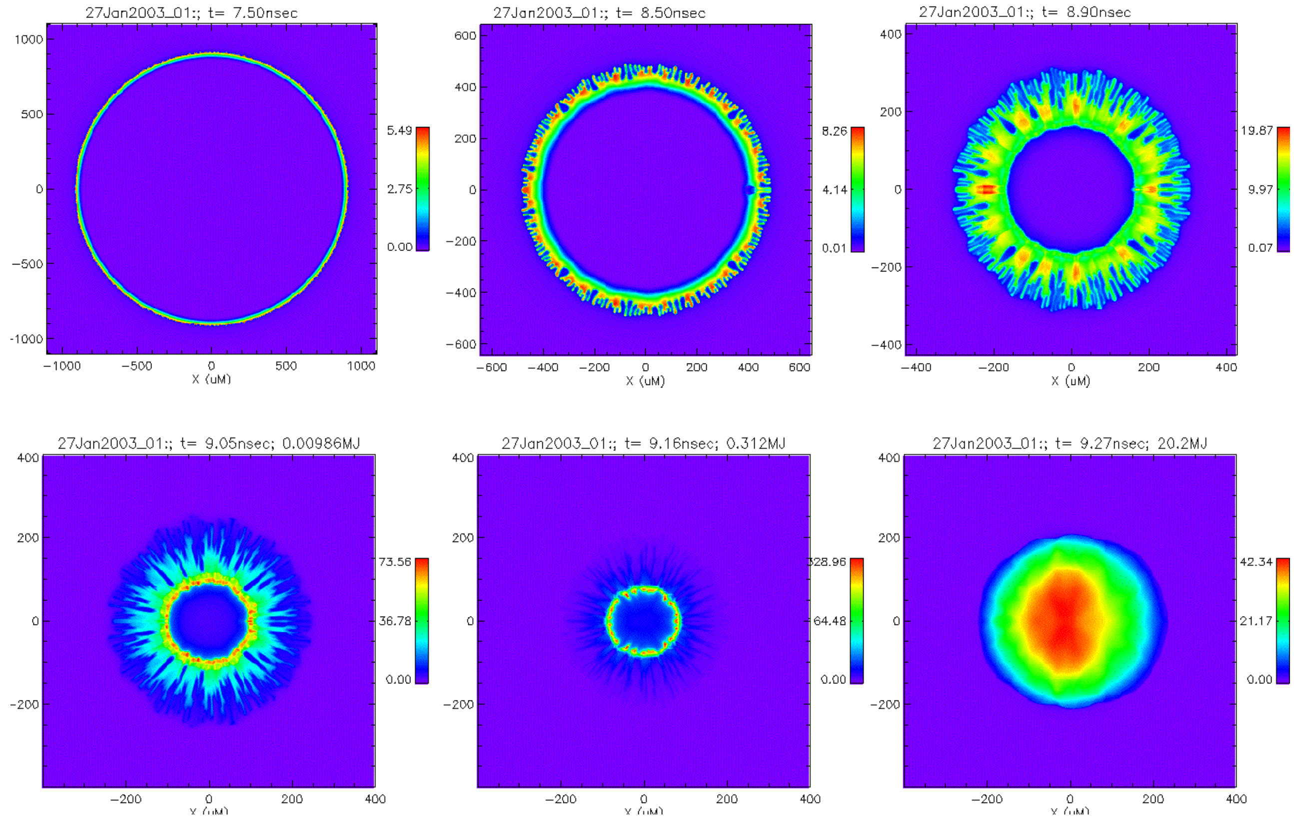
- High-resolution 2D simulation of NIF pellet implosion.
- Gain degraded from ~ 35 to 17 by Instability seeded by laser & target imperfections



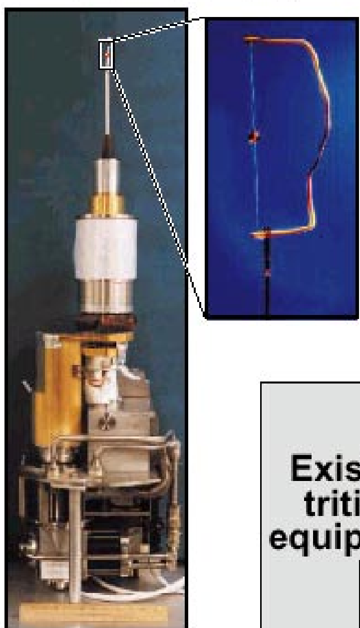
Big problems require large computers

“Self-built” 256-processor supercomputer cluster “NOX”
(Listed as one of the world’s Top100 supercomputers)

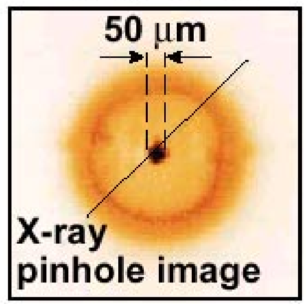
LLE is performing direct-drive layered cryogenic D_2 target experiments

UR LLE

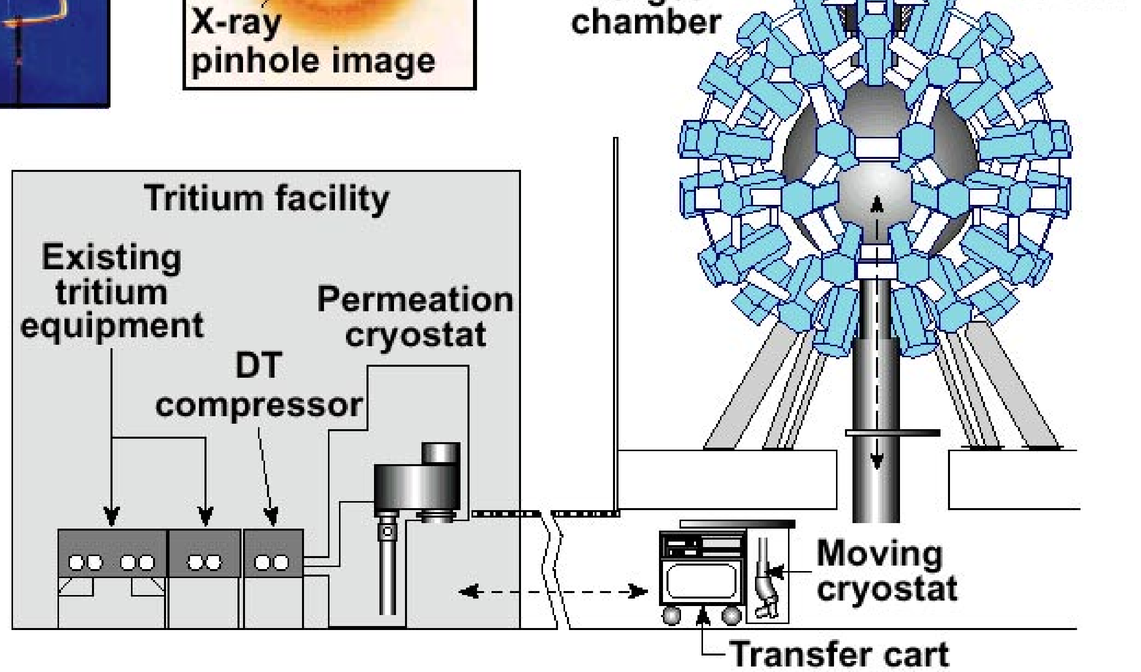
Target positioning and mounting



Target shot



Omega 30 kJ implosion facility



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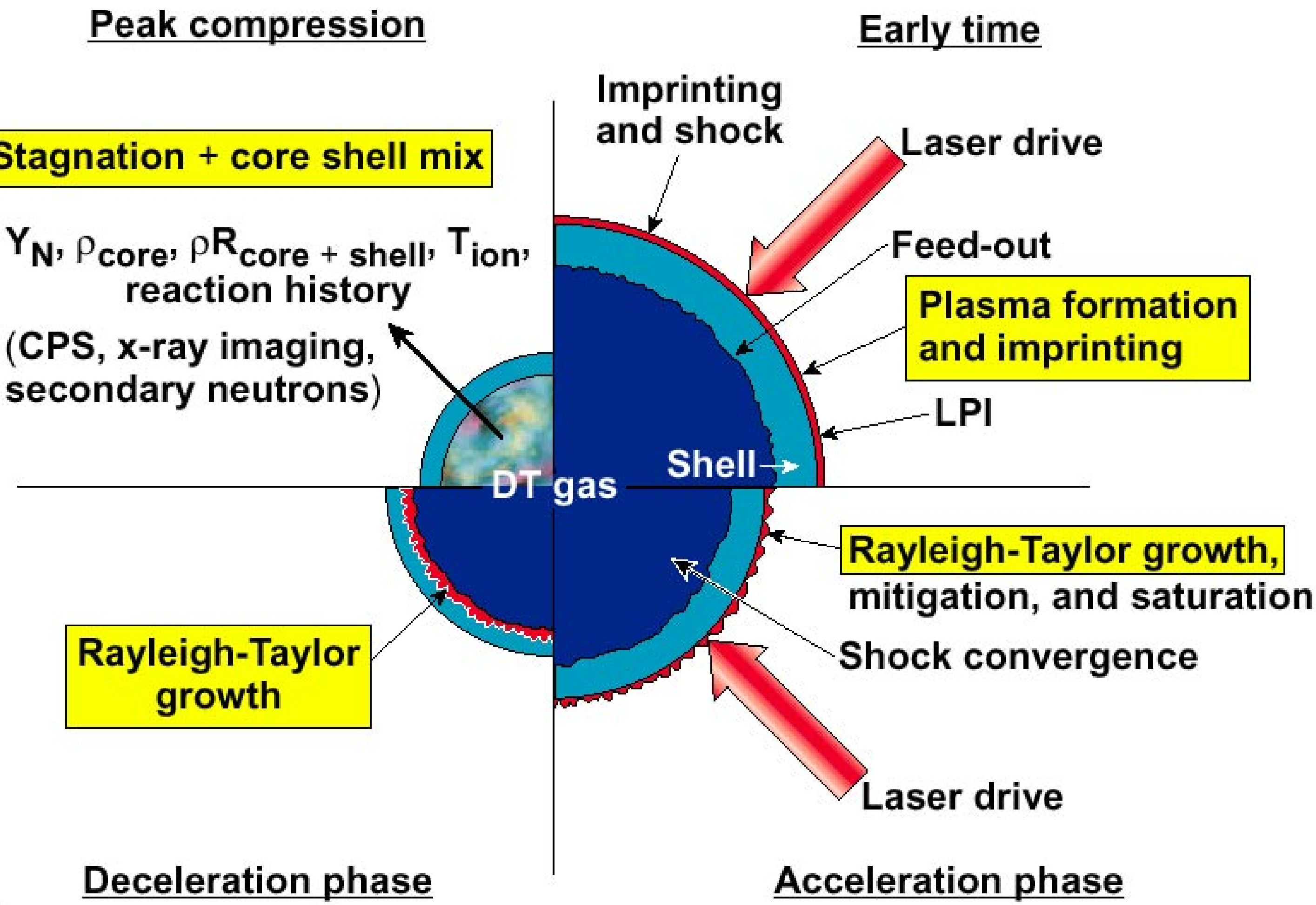
LLE's target physics research program combines all aspects of direct-drive ICF



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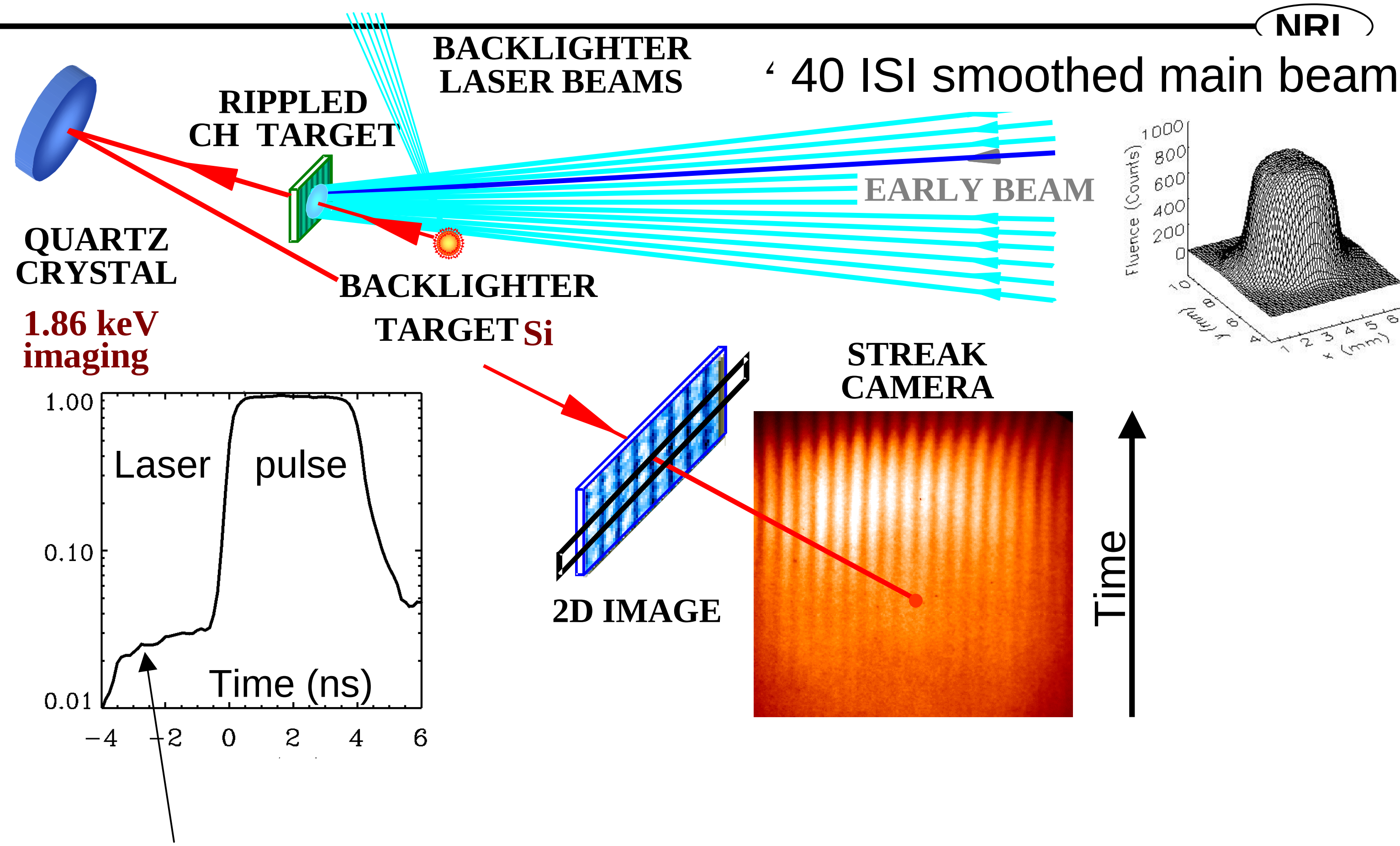
Planar target experiment to investigate hydrodynamic instability

- 40 ISI smoothed main beams



Low intensity “foot” pulse
vary # beams & laser bandwidth

Nike KrF facility

Experimental results show a thin high-Z outer layer (120-nm Pd) substantially reduces the effects of laser non-uniformity.

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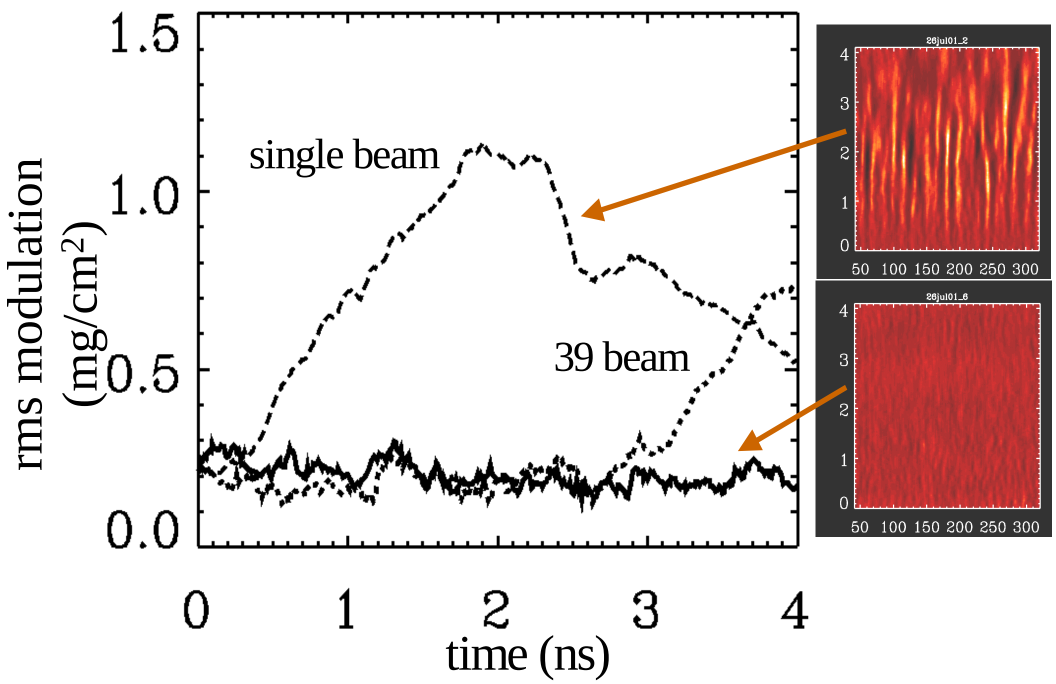
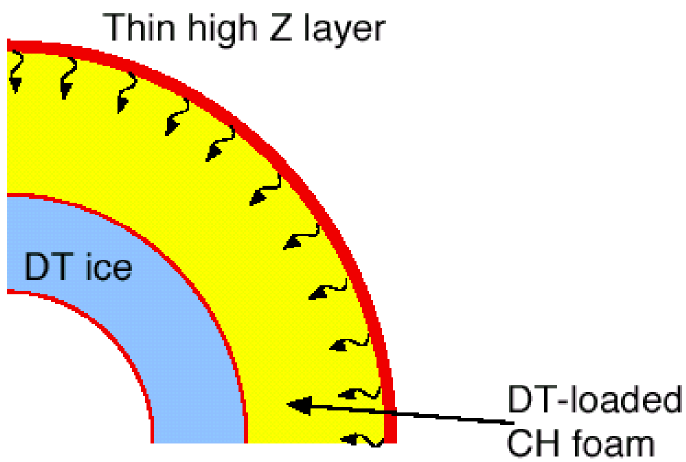
Decrease in imprint by Pd layer is larger than the effect of increasing number of laser beams from 1 to 39



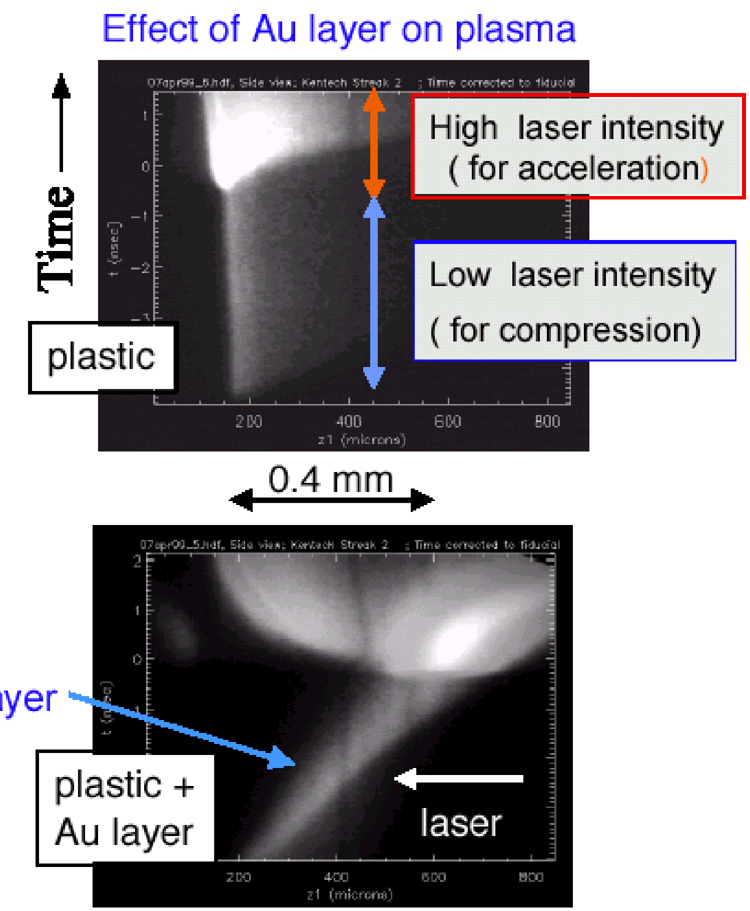
CH target
(single beam "foot")

CH with 120 nm Pd
(single beam "foot')

- X-rays from the high-Z layer creates a large plasma at early time that smoothes laser nonuniformity during the low intensity foot



High-Z layers are now used in pellet designs: early time indirect drive



X-rays from Au layer

Side-on views of x-ray emission

One-dimensional calculations indicate we can obtain gains >100 with high-Z coated targets

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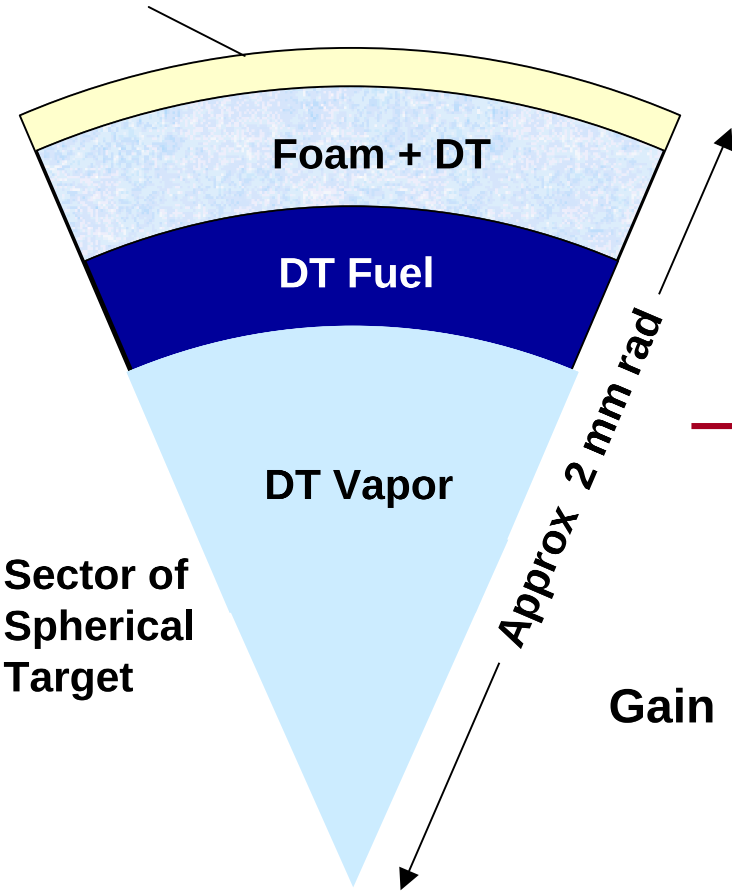
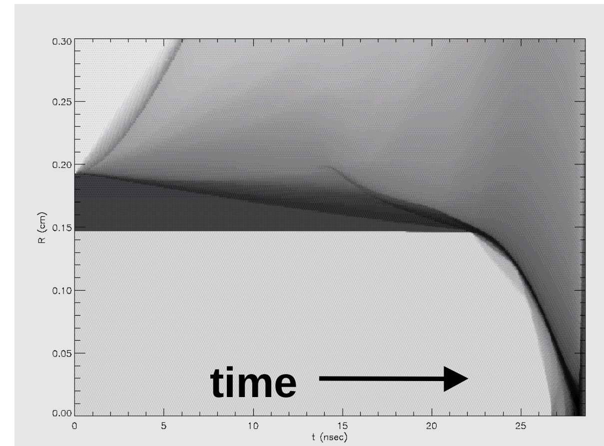
Thin (300-1800 Å) High Z coating

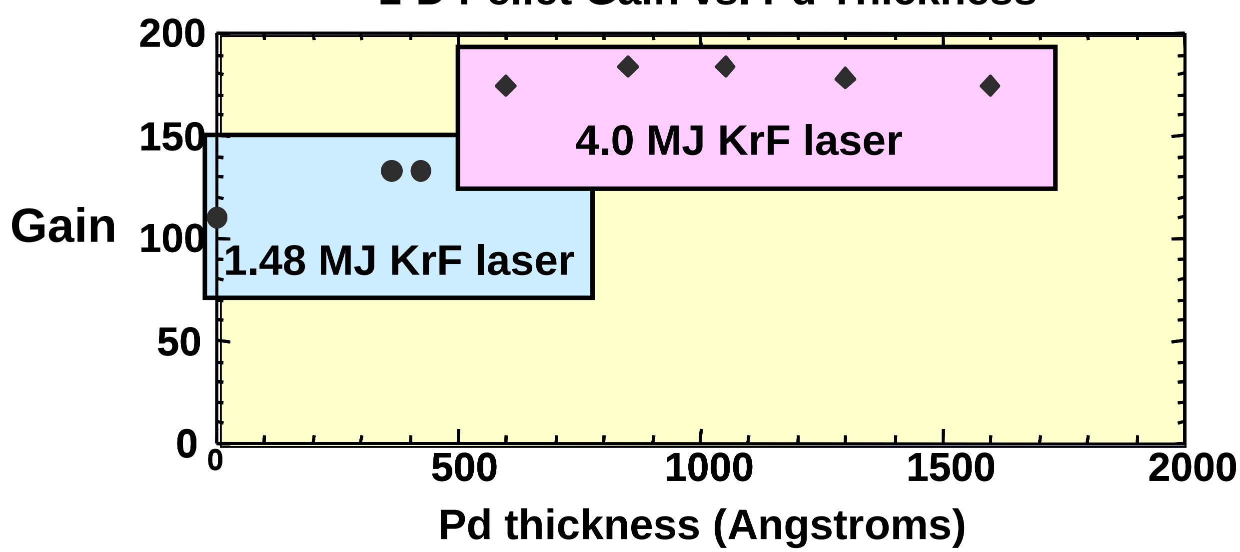


Sector of Spherical Target

1D implosion using NRL FAST code



1-D Pellet Gain vs. Pd Thickness



High-gains can be traded for increased stability by using a larger amplitude “foot” pulse that increases the shock heating

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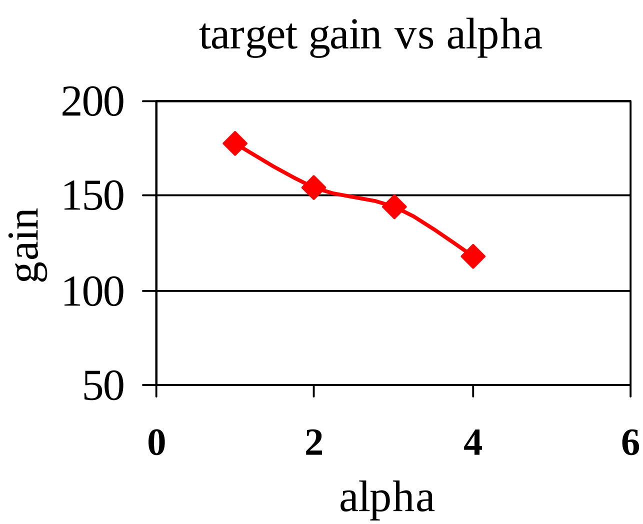

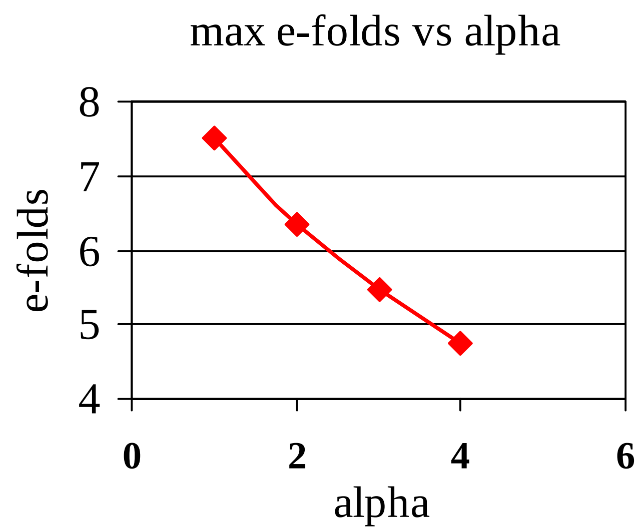

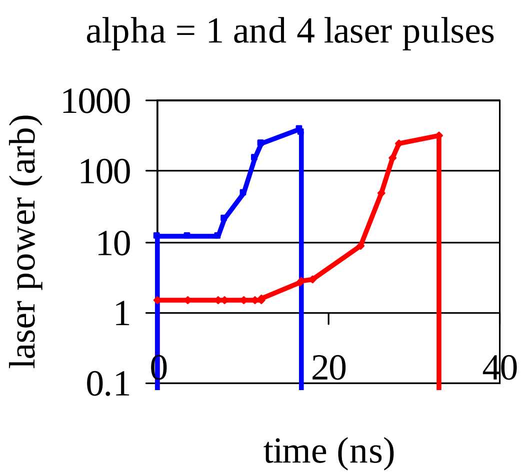

- DT loaded foam ablator
- KrF with zooming
- 2.6 MJ

A spiked prepulse can be used for both imprint mitigation and adiabat control

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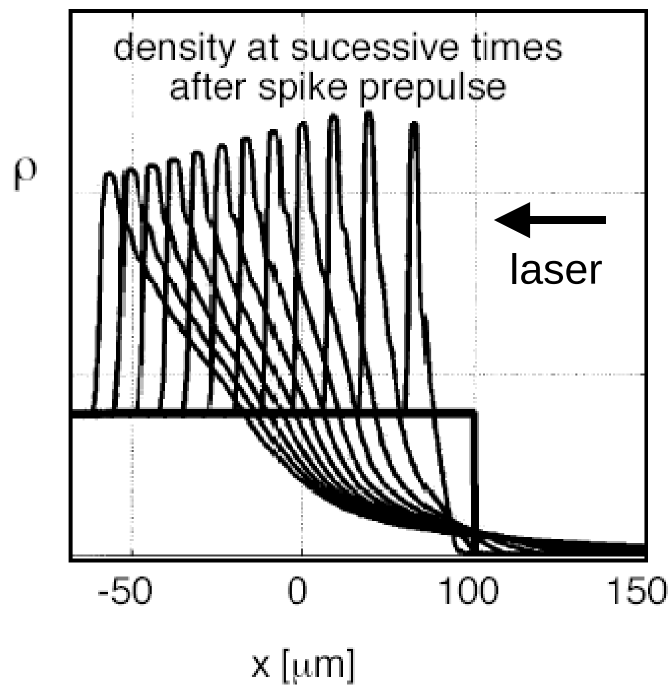
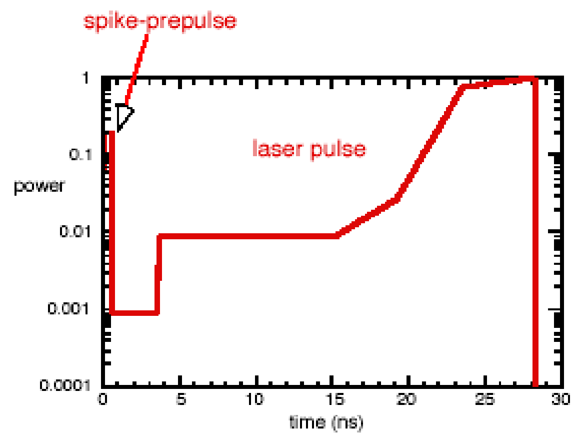




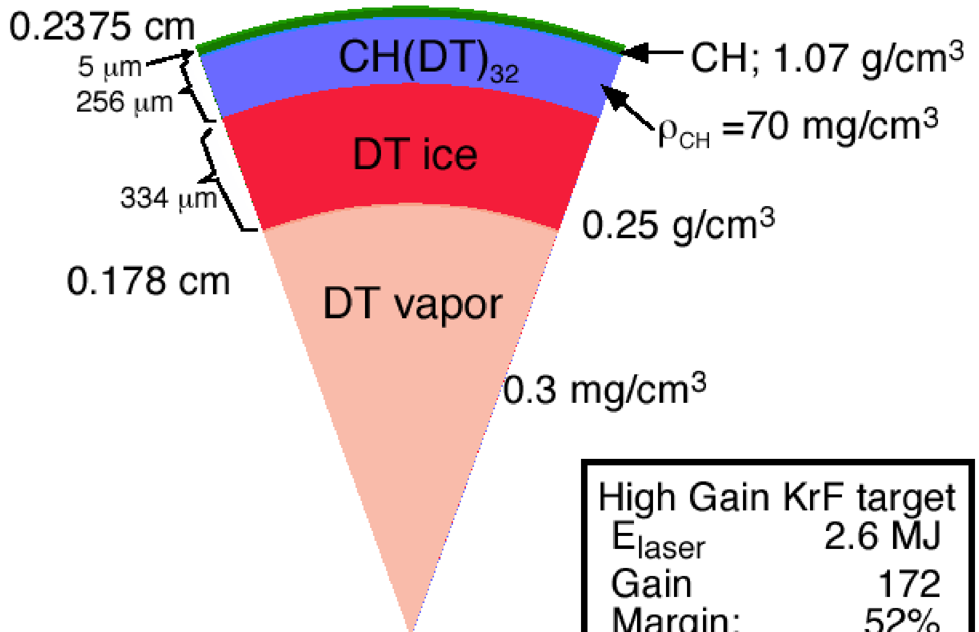
Spike repulse drives a decaying shock through the pellet

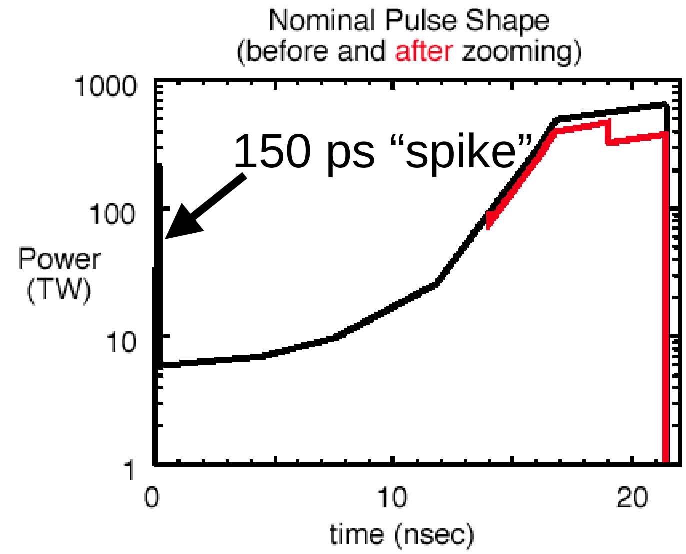
1. The rarefaction behind produces a stabilizing density gradient on the outside of the pellet

2. The spike preferentially preheats the ablator "tailored adiabat"

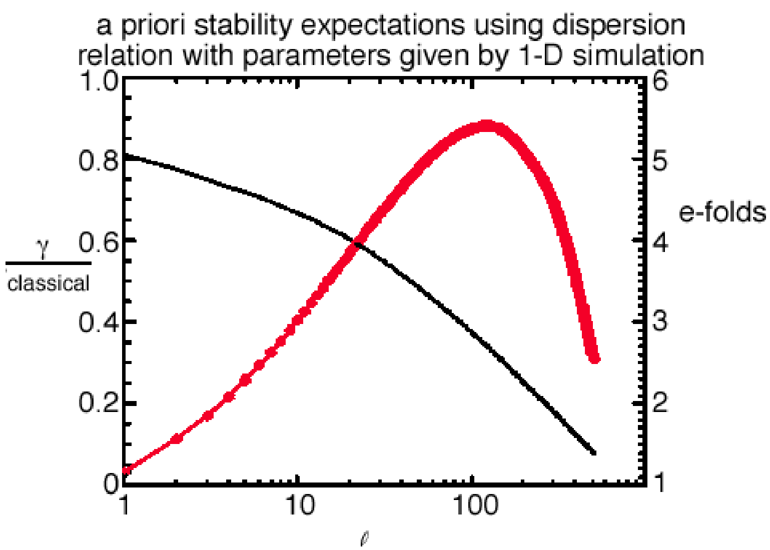
Application to pellet design is being explored by LLE, LLNL & NRL

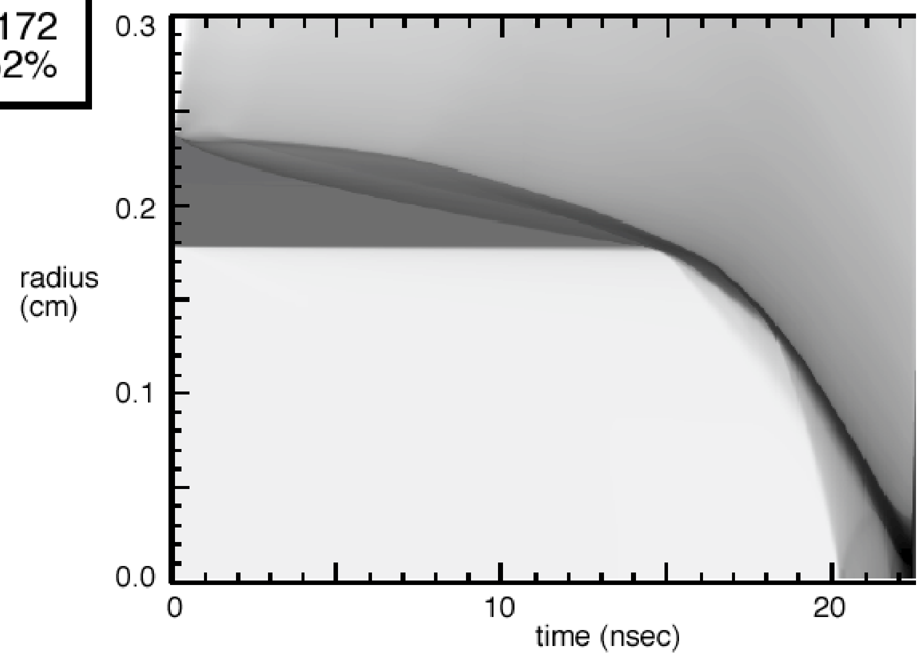
High Gain KrF pellet with stabilizing "spike"





High Gain KrF target	
E_{laser}	2.6 MJ
Gain	172
Margin:	52%





Use of laser pulses with a single picket ahead of the main pulse may allow increased stability (calculations by J. Perkins, LLNL)

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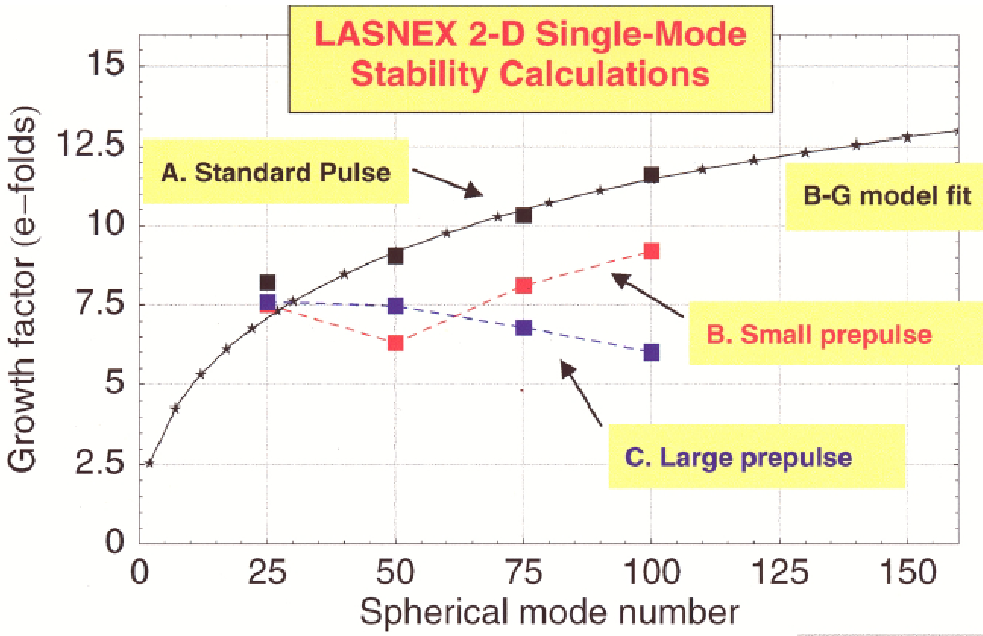

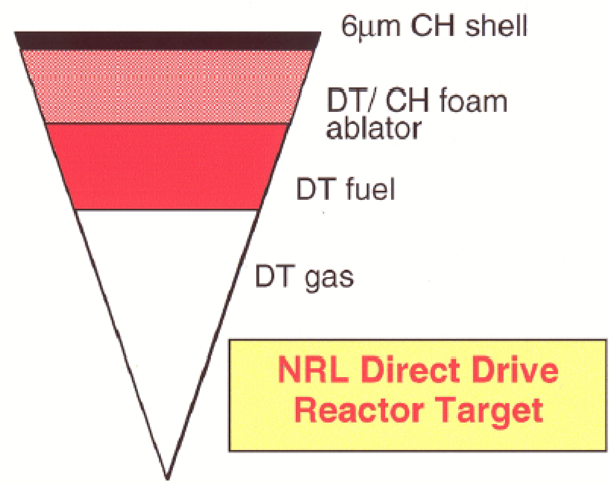

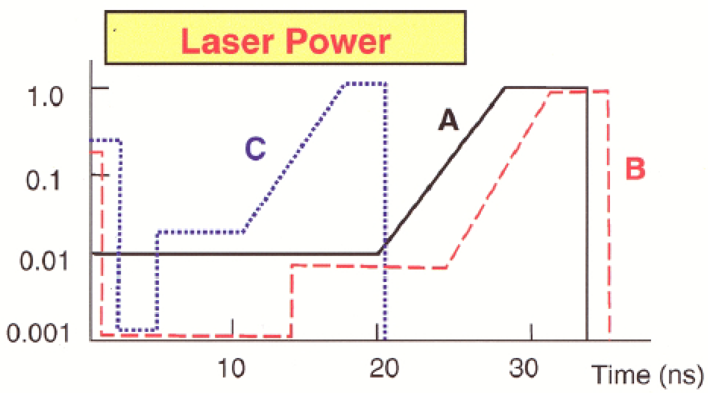

Pulse Shape	Laser (MJ)	Yield (MJ)	Gain	Max Shell Breakup Fraction (%)
A. Standard	2.4	430	180	83
B. Small prepulse (small "picket)	2.5	420	170	21
C. Large prepulse (large "picket")	3.1	360	110	2

High-resolution integrated 2-D simulations give gain of 160 with laser and outer surface nonuniformity

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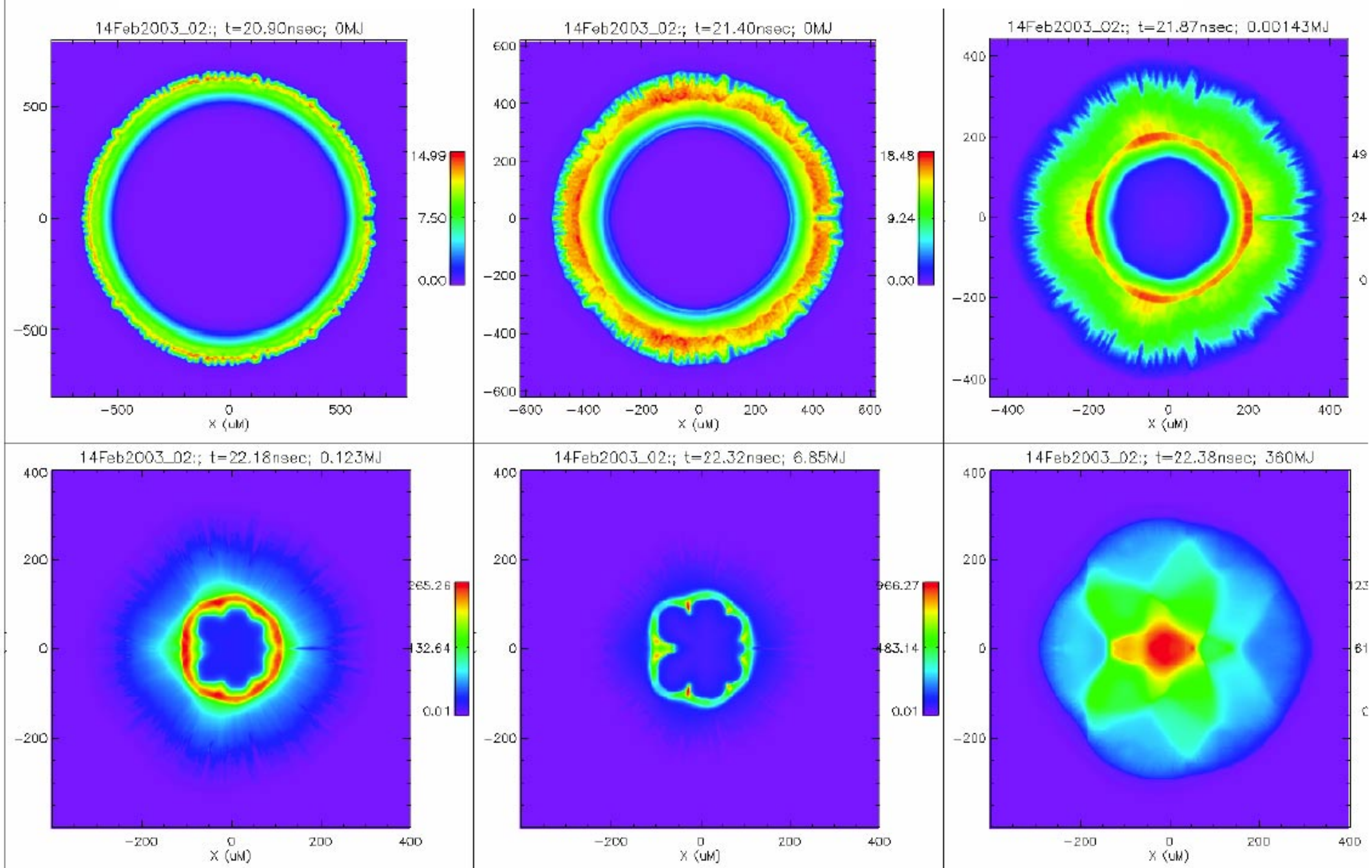
Outer (0.125um rms) & ISI (1Thz) perturbations included



images of density at six different times during the implosion

- Nonuniformity amplitudes during intial shock transit calculated from single mode studies
- Multimode-calculation of shell acceleration, stagnation and burn

Gain still high (160) with addition of inner surface nonuniformity

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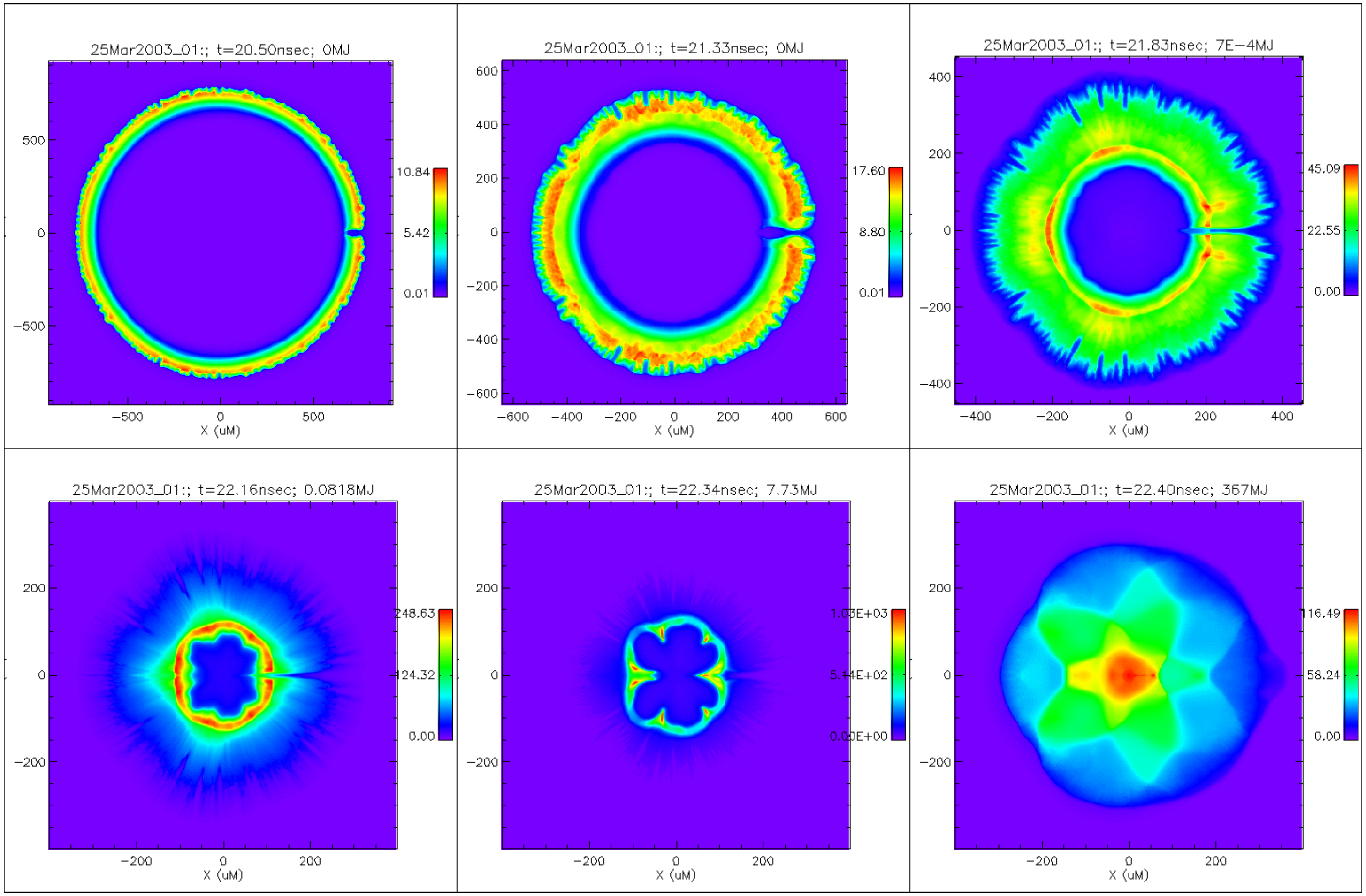
Inner (1um rms) & Outer (0.125um rms) & ISI (1Thz) perturbations included



Latest high gain designs are robust per the 2-D simulations

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- May be able to accommodate reduced inner and outer pellet surface quality
- May be able to relax laser parameters (uniformity & energy)
- Work in progress: parametric studies & 3-D effects.