Laser direct-drive IFE targets: sensitivity to fabrication and drive imperfections*

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Overview of direct-drive IFE studies

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We've examined the robustness of the 500kJ FTF pellet designs using hydrocode simulations. In addition, we have begun studies of a ~300kJ higher gain shock ignited target.

Interested in the effects of different perturbations:

target: inner and outer surface perturbations

laser: drive asymmetry and laser imprint

FTF

500 kJ FTF targets: gain and stability vary with pulse shape

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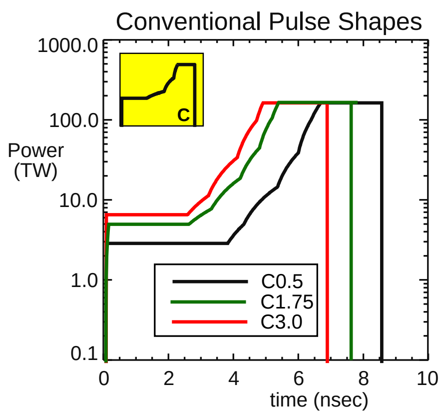
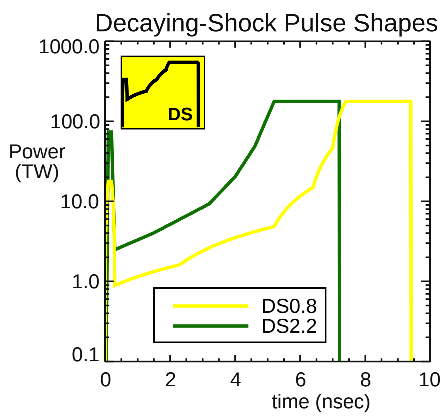
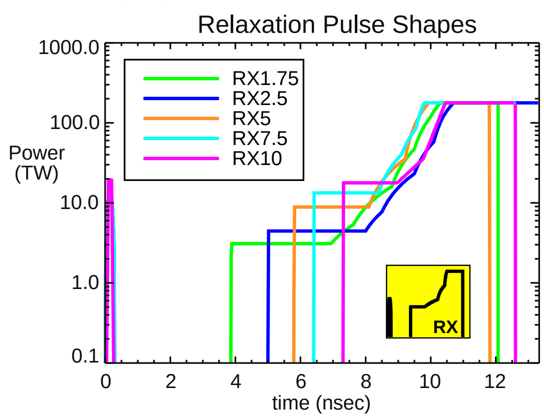
The targets designs are based on a single pellet driven by different pulse shapes; I_{max} ~2-2.5 x 10^{15}W/cm^2

- A higher pulse foot gives higher adiabat, more stability, less gain
- Adiabat shaping is achieved using an early-time spike in the RX or DS pulses.







Pulse	Gain 1d	Gain 2d (hi-res)	Foot[5] (%)	<α>[3]
C0.5	99	0	0.5	2.3
C1.75	66	47	1.75	4.5
C3.0	42	--	3.0	6.2
C4.0	20	--	4.0	7.3
RX0.5	101	--	0.5	2.1
RX1.75	79	0.7	1.75	3.0
RX2.5	75	66	2.5	3.4
RX5.0	63	55	5.0	4.6
RX7.5	49	3.4	7.5	5.9
RX10	16	0.8	10.0	6.8
DS0.8	69	62	0.8*	3.5
DS2.2	49	6.5	2.2*	5.6

(1) From 1-D RT dispersion relation $0.9\sqrt{kat} - 3kV_{ablation}$

(2) In-flight aspect ratio, measured at 2/3 R_0.

(3) Mass averaged from peak density to 1/e peak density, at peak velocity.

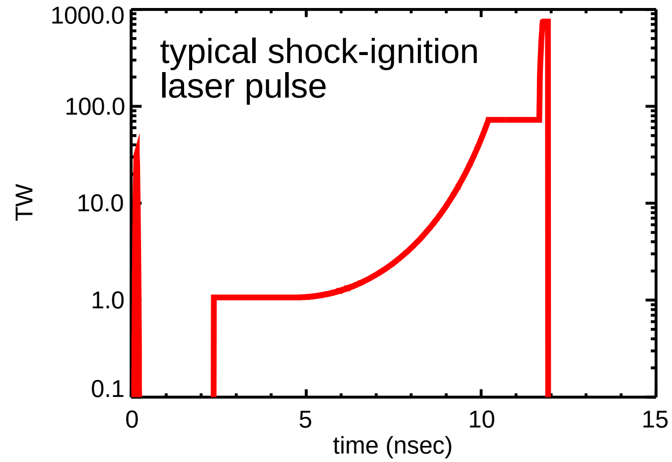
(4) Fraction of peak kinetic energy remaining when gain=1.

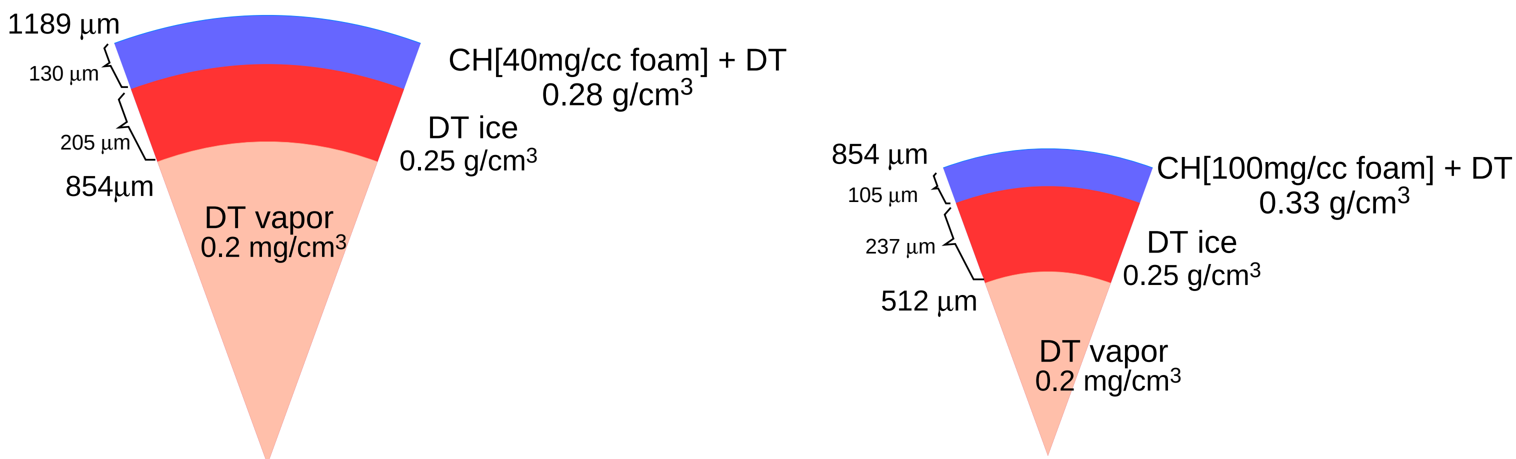
*(5) Foot power/Main pulse power; *for DS pulses: Spike energy/Total Energy.*

Shock Ignition targets: ~300 kJ KrF pulse

Shock ignition targets in the range of 200-300kJ laser energy have been studied*. In shock ignition, the (thick) target is driven on a **very low adiabat** but to **low velocities**. A final high-power short duration spike in laser power creates a shock that ignites the target.

1D design work indicates gains of order 100 possible for E_{laser}~200kJ, and fairly robust ignition and burn conditions for E_{laser}~300kJ.





(to scale)

480 kJ FTF target

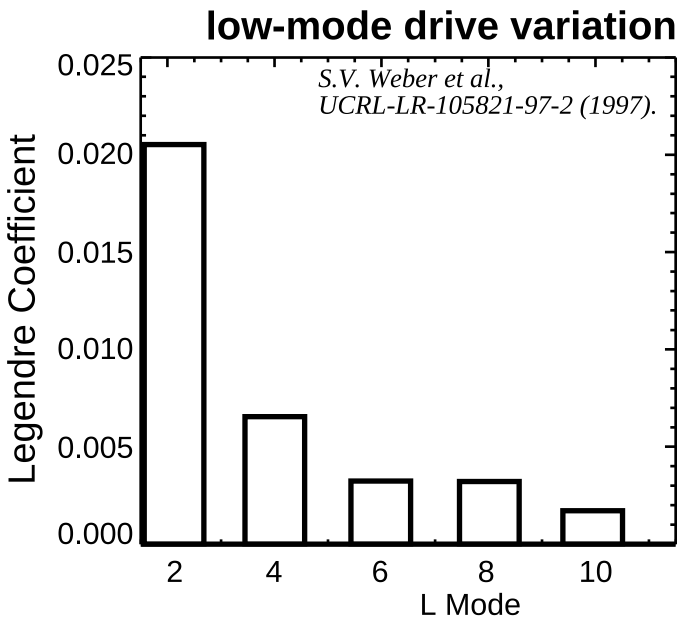
(to same scale)

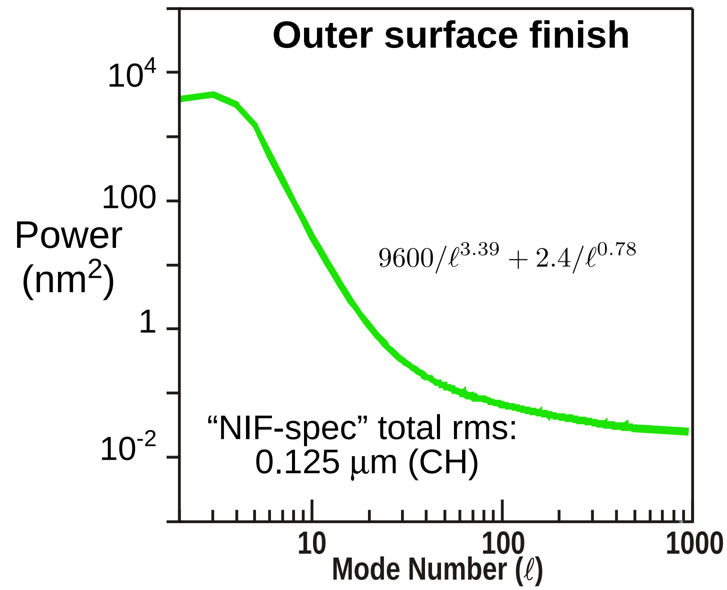
200-300 kJ Shock-Ignition target

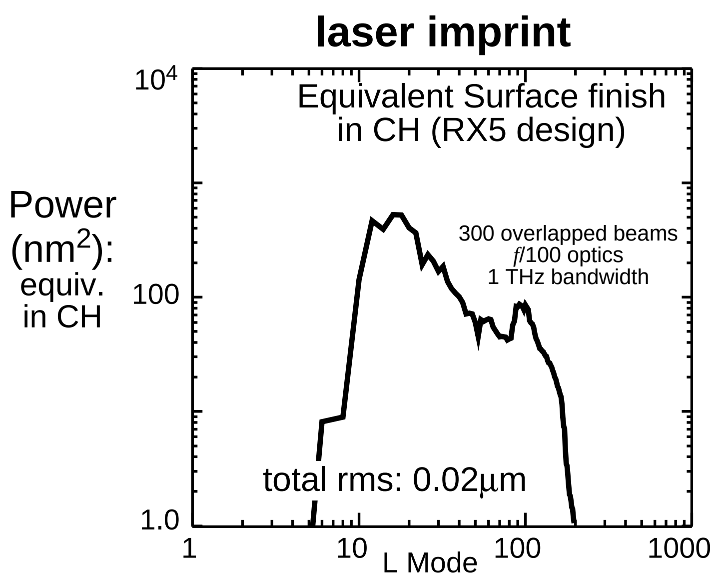
Not shown: both targets will also have a thin CH overcoat

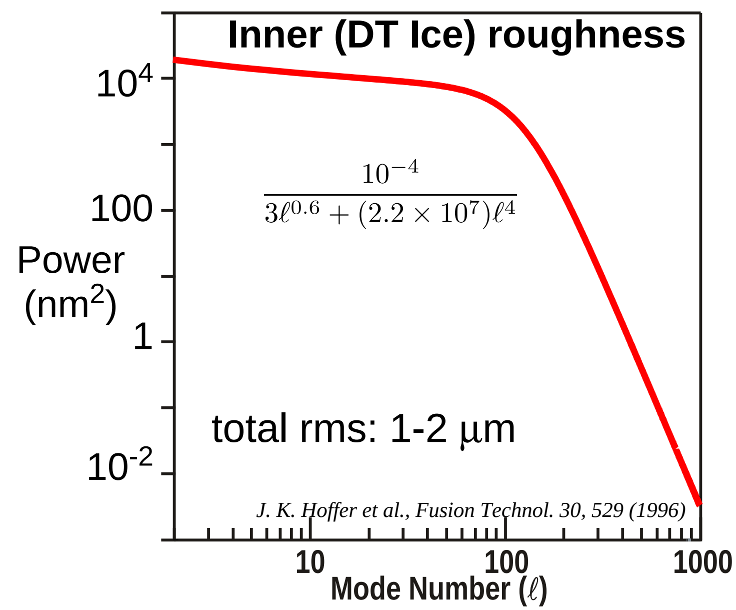
*R. Betti et al., Phys.Rev.Lett. **98**, 155001 (2007)*

Target and laser perturbations have been considered









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Drive perturbations have been modeled with static drive asymmetry

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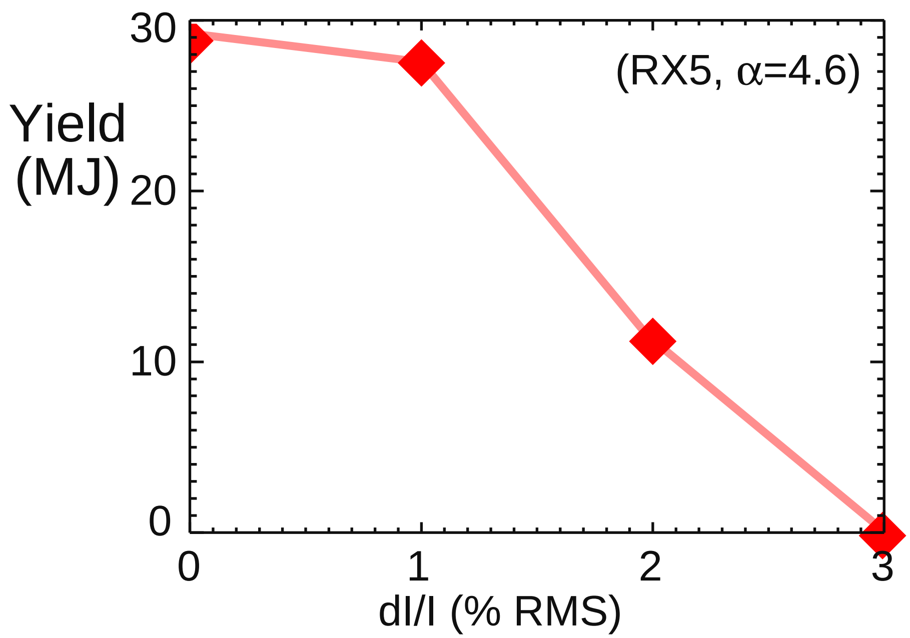
These simulations account for drive asymmetries produced by the aiming configuration, energy imbalance and mis-alignment among the laser beams. The designs become sensitive to low-mode intensity perturbations at a level of 1-2%.

low mode (ℓ=2-16) modeling



A consistent, time-dependent model is being added to the FAST code

low-mode modelling predicts robustness of FTF target to inner surface roughness

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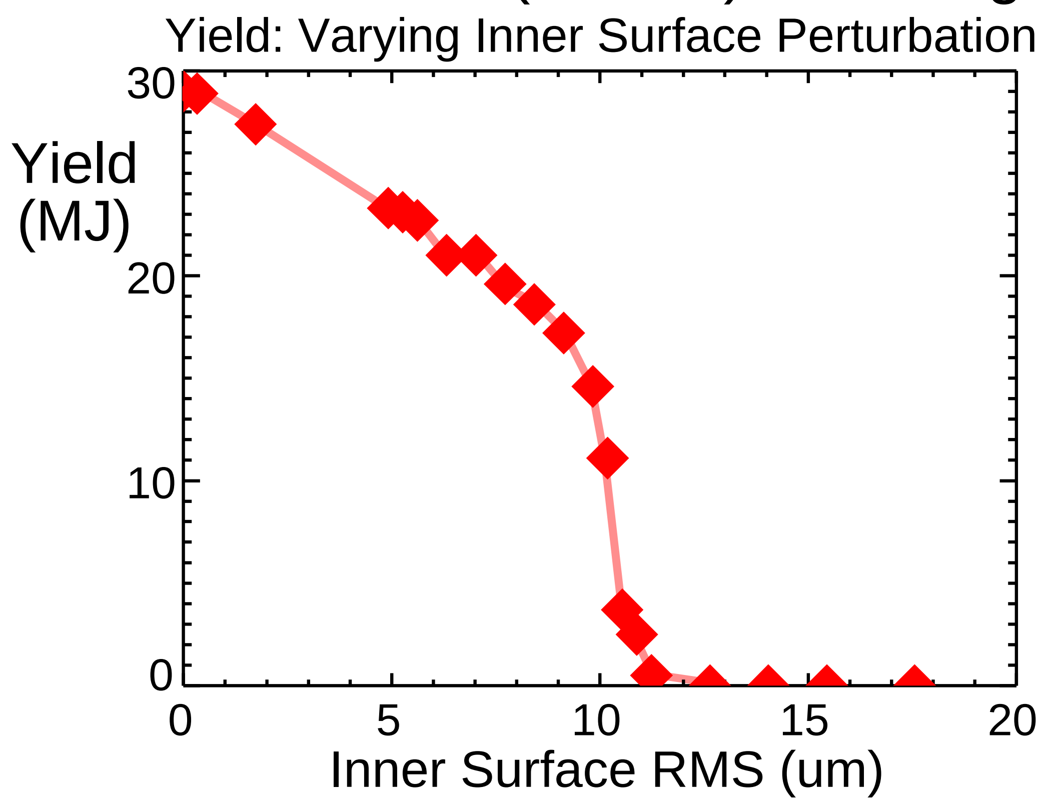
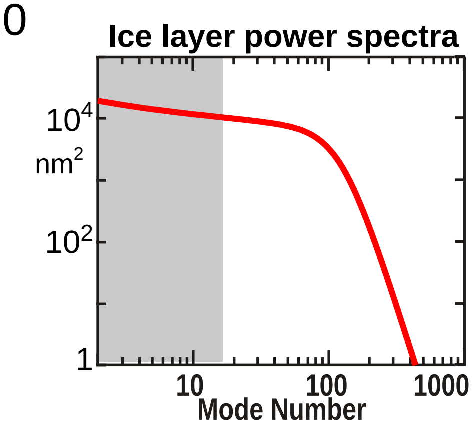
low mode (ℓ=2-16) modeling



Modes do not grow until shock arrives at the rear surface at the end of the compression phase
(so: less time to grow)
but: amplitudes are initally larger in ℓ=10-100 range



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Lower resolution studies show increasing sensitivity for higher adiabats

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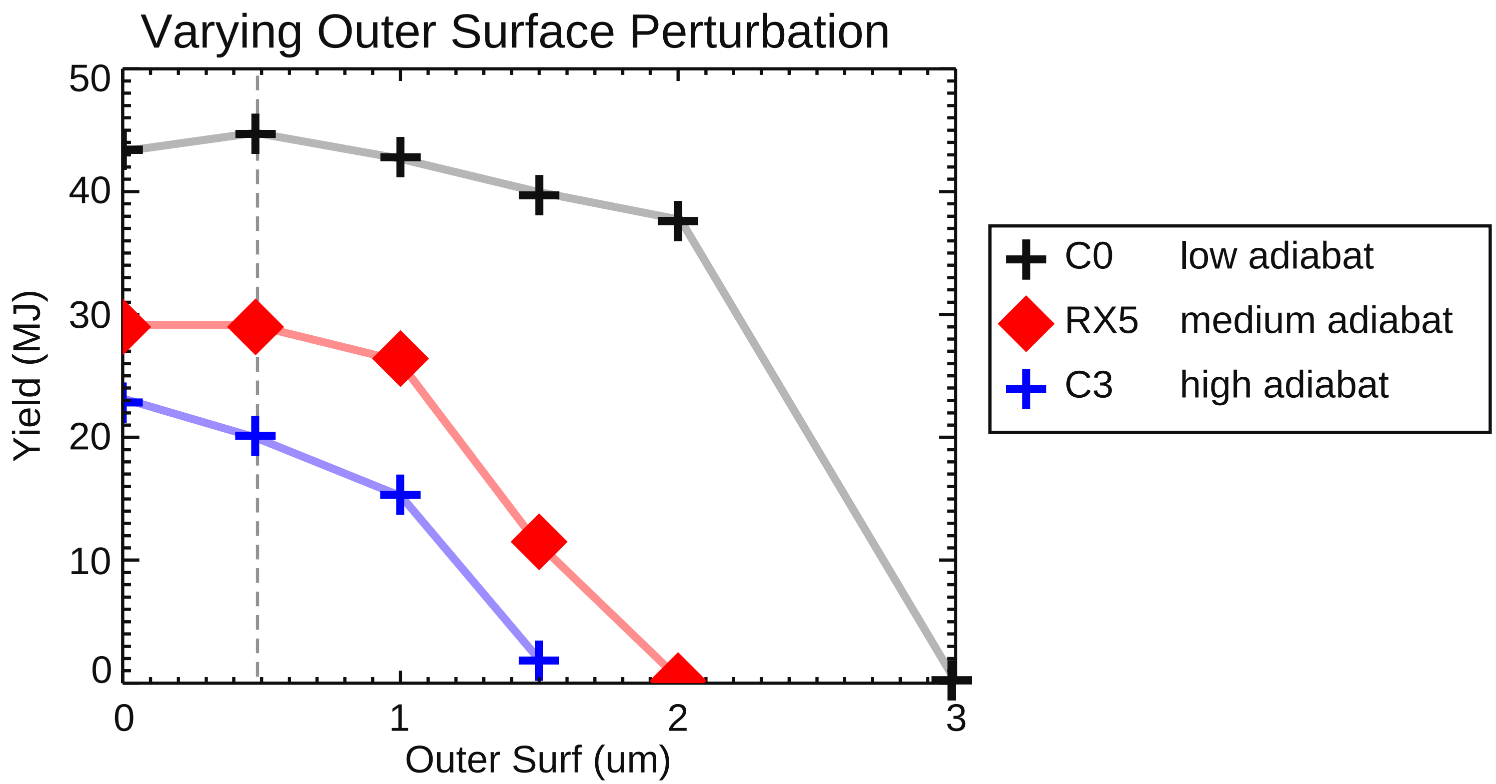
low mode (ℓ=2-16) modeling



Low-resolution 2D simulations (resolving modes ℓ=2-16) show that designs with higher adiabat (higher stability, less gain) are more sensitive to low-mode perturbations.

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High-resolution 2D simulations with realistic ("NIF-spec") outer surface perturbations predict little gain degradation

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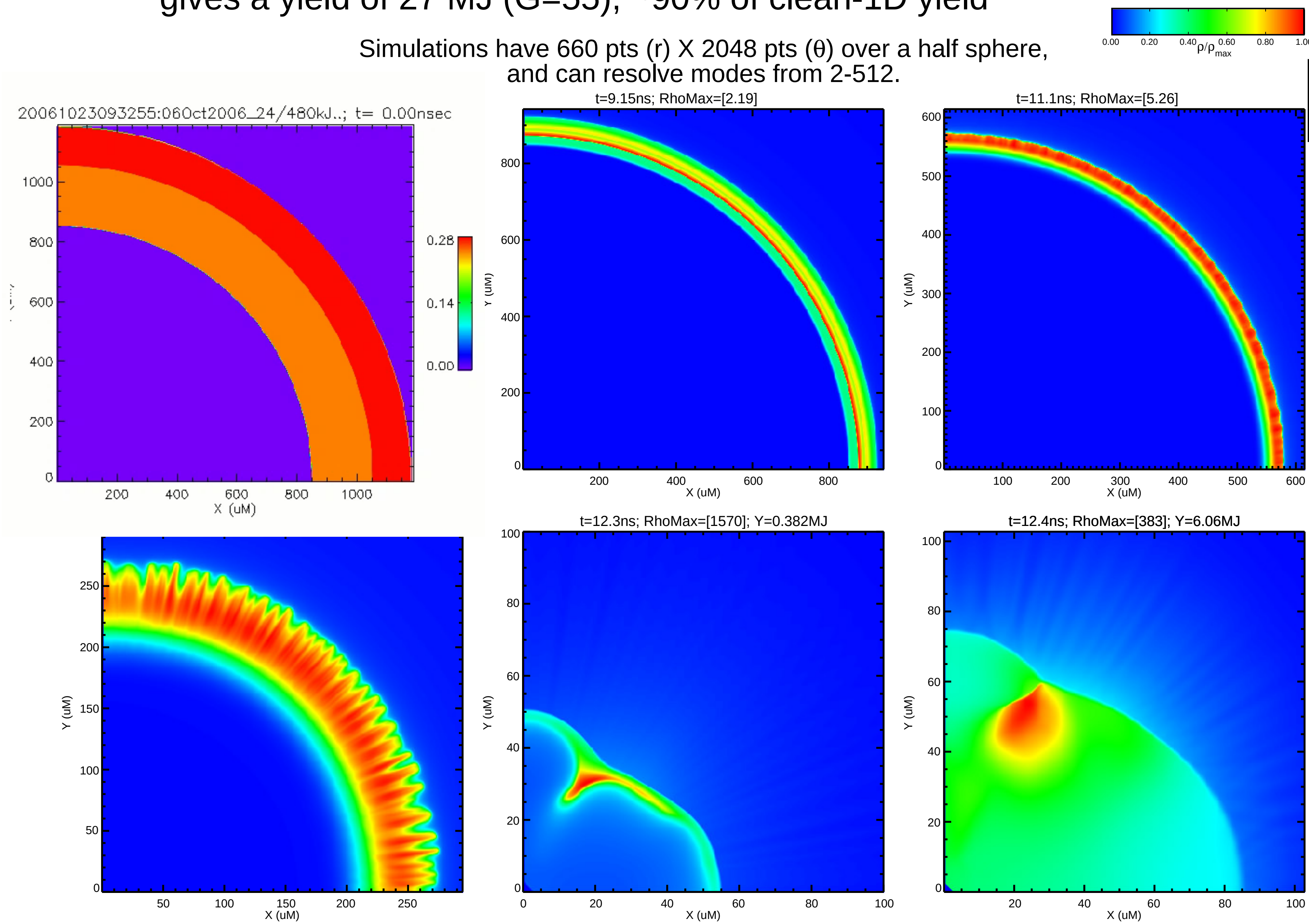
Result: With NIF-spec.-equivalent outer surface finish, the RX5.0 pulse gives a yield of 27 MJ (G=55), ~90% of clean-1D yield

Simulations have 660 pts (r) X 2048 pts (θ) over a half sphere, and can resolve modes from 2-512.

RX5 design

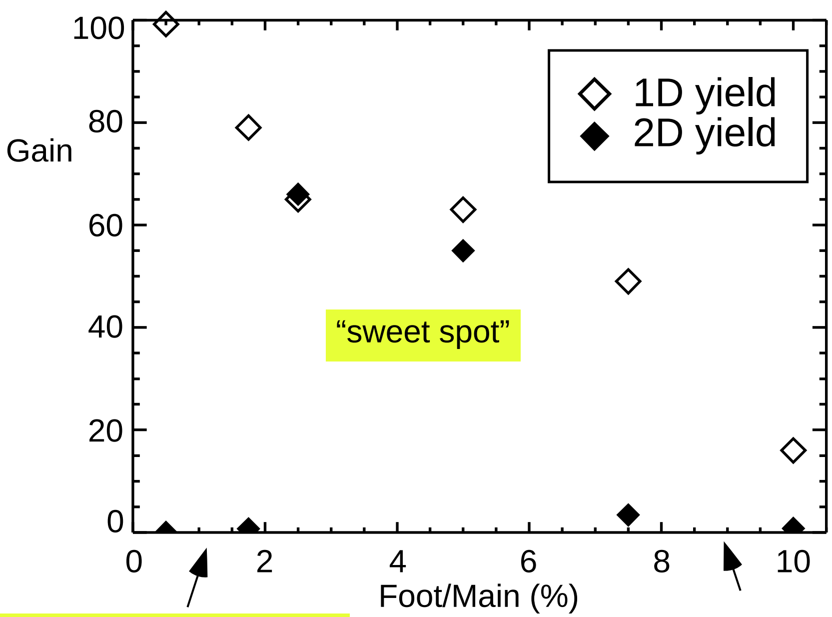


20061023093255:06Oct2006_24/480kJ.. RX3; Y=27.2MJ

Finding the optimum gain in 2D: using RX pulses

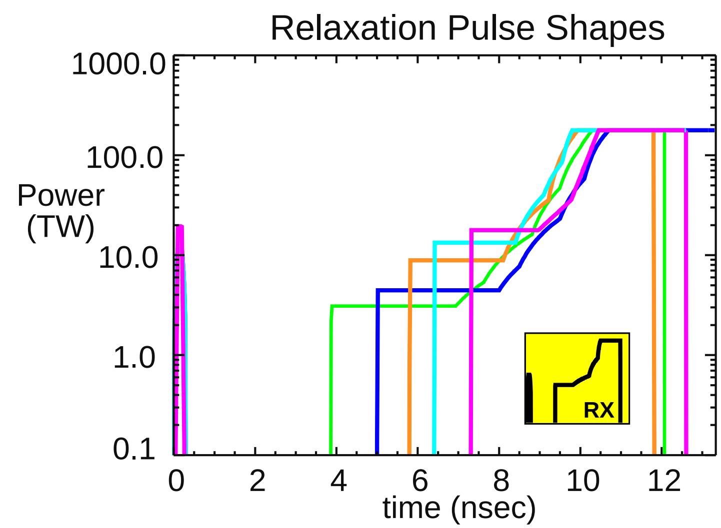
Increasing the foot pulse amplitude increases the adiabat
- decreases the gain (1D)
- reduces RT at high mode (2D)
- increases sensitivity to low-mode asymmetry (2D)

Relaxation pulse (RX) family of FTF designs

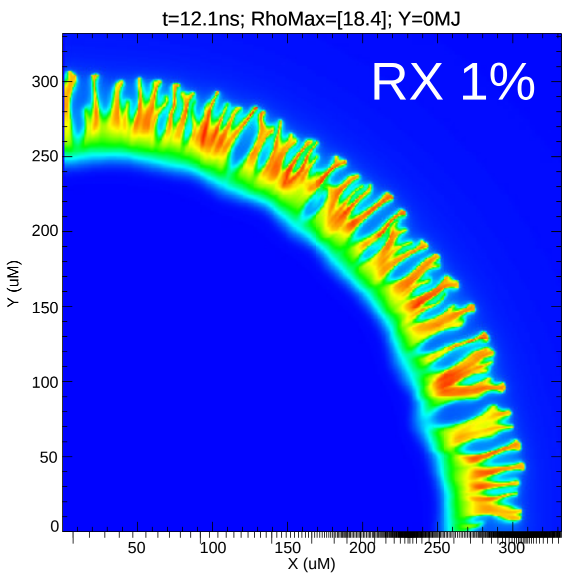


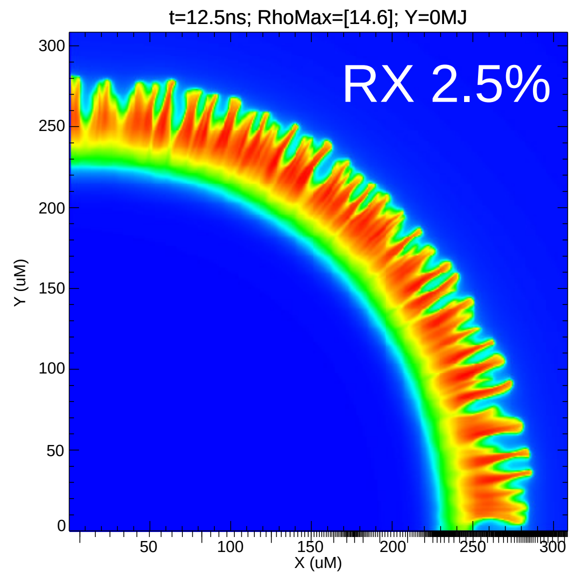
high mode growth dominates:
target shreds

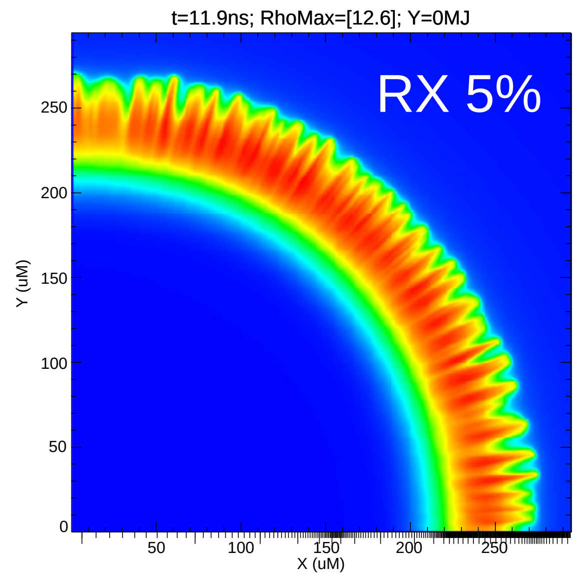
low mode growth dominates:
target doesn't ignite

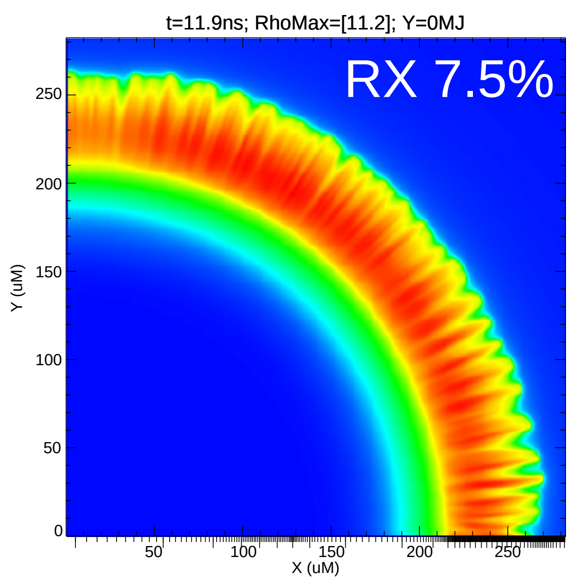


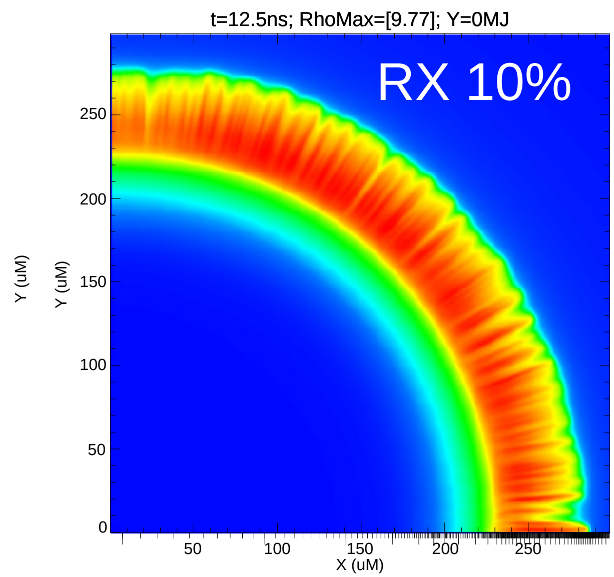
FTF After targets have gone 75% towards stagnation, ablative stabilization effects are evident





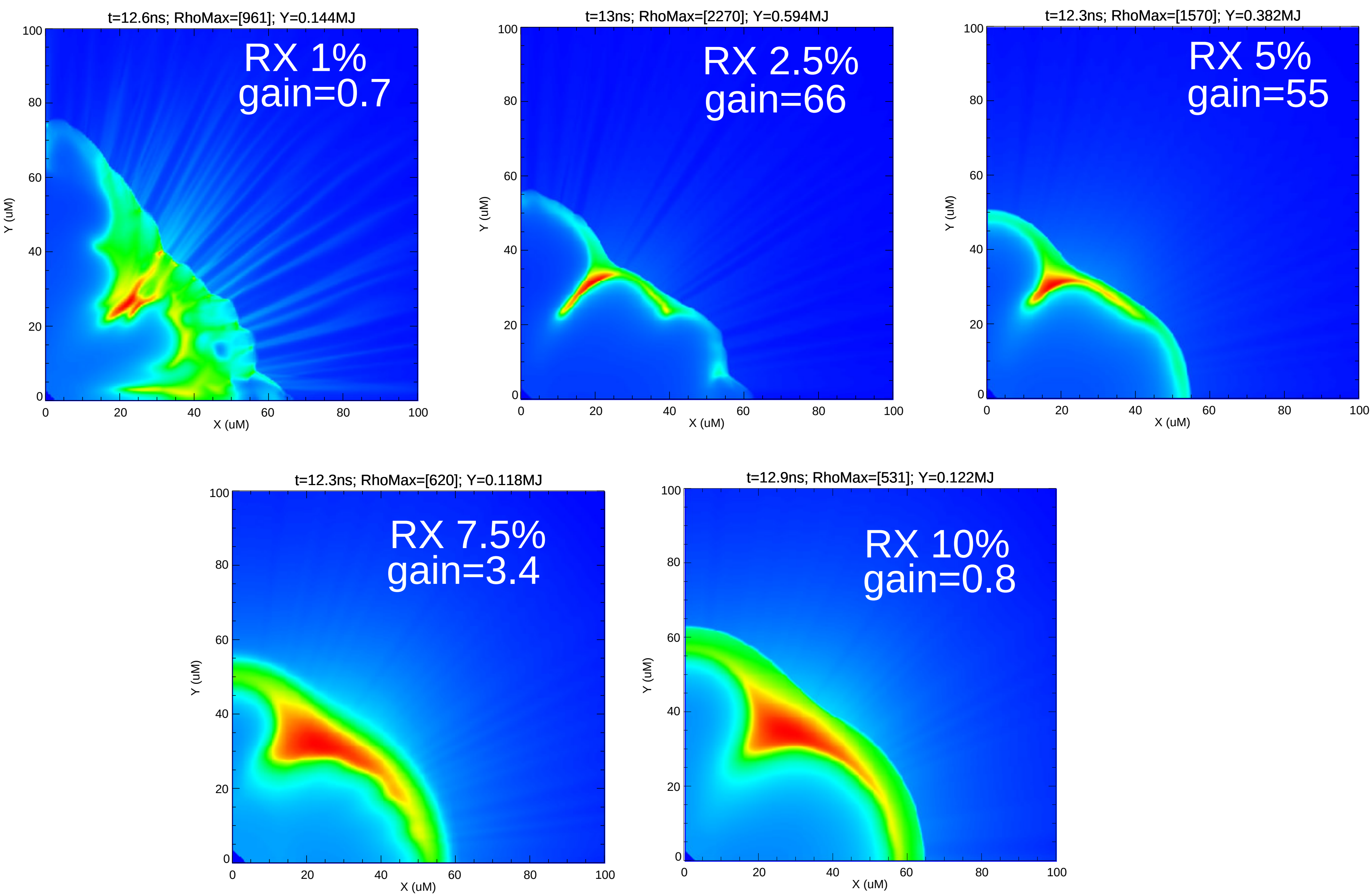






FTF

As the targets near gain 1, they have either failed or are burning well



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In general, higher resolution studies show more sensitivity to outer surface perturbations

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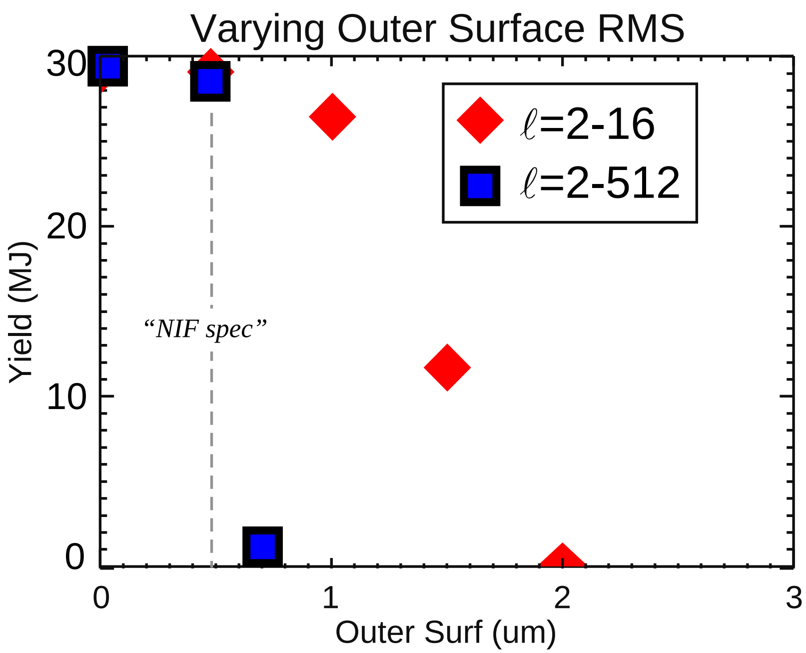
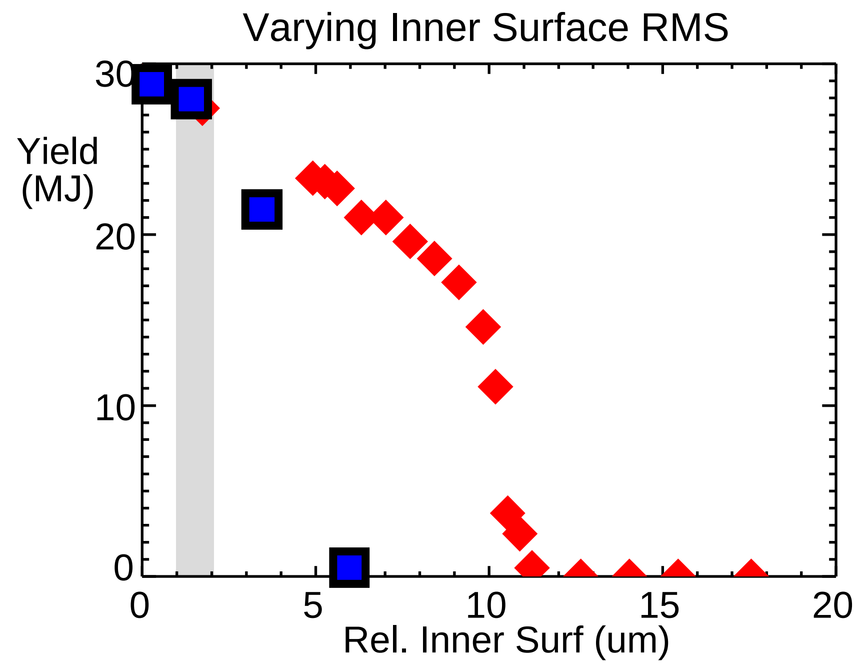
RX5 design





High-resolution 2D simulations (resolving modes ℓ=2-512) show that designs are more sensitive to perturbations than the low mode studies suggest. While inner surface roughness sensitivity leaves some margin for error, the design is close to a "cliff" with regards to outer surface sensitivity.

FTF

High resolution simulations show that the targets can survive expected surface perturbations and still give significant yield.

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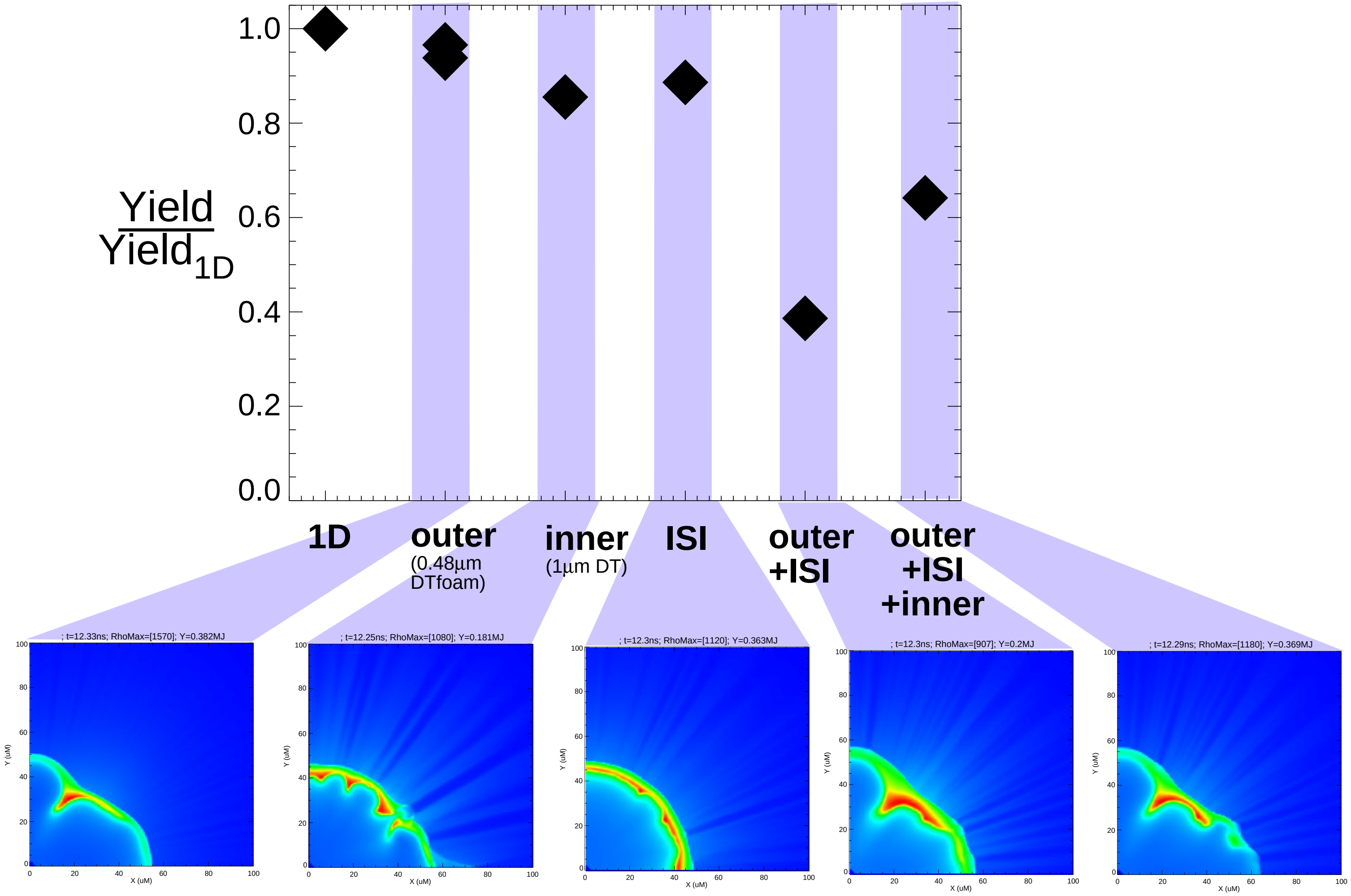
high-resolution simulations resolved with modes ℓ=2-512

RX5 design



However, the large (implied) scatter in the results, as well as the stagnation images, indicates that low-modes dominate the results when outer surface perturbations are applied.
This implies a need for 3D simulations.

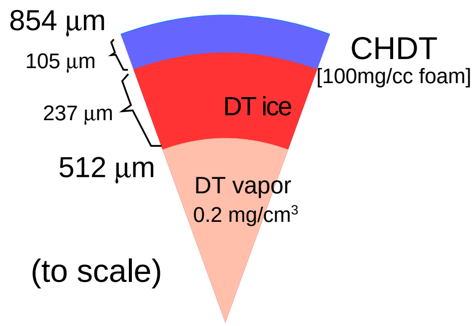
SI

Shock Ignition studies: ~300 kJ KrF pulse

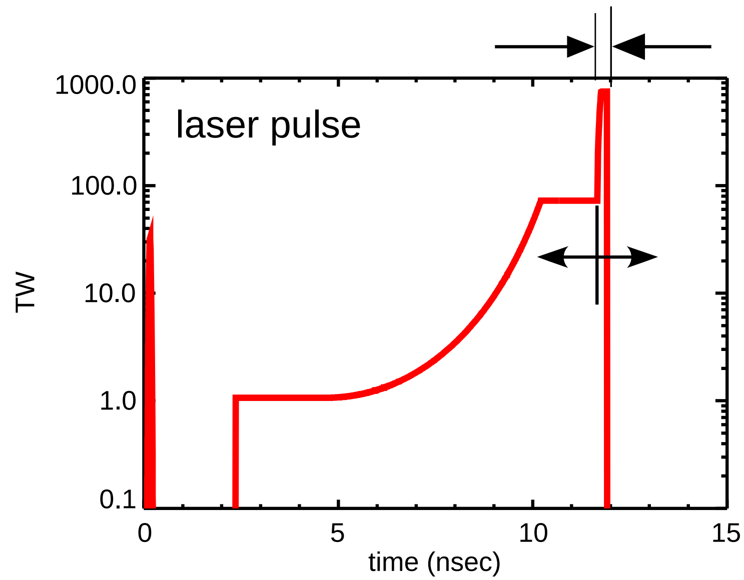
NRL

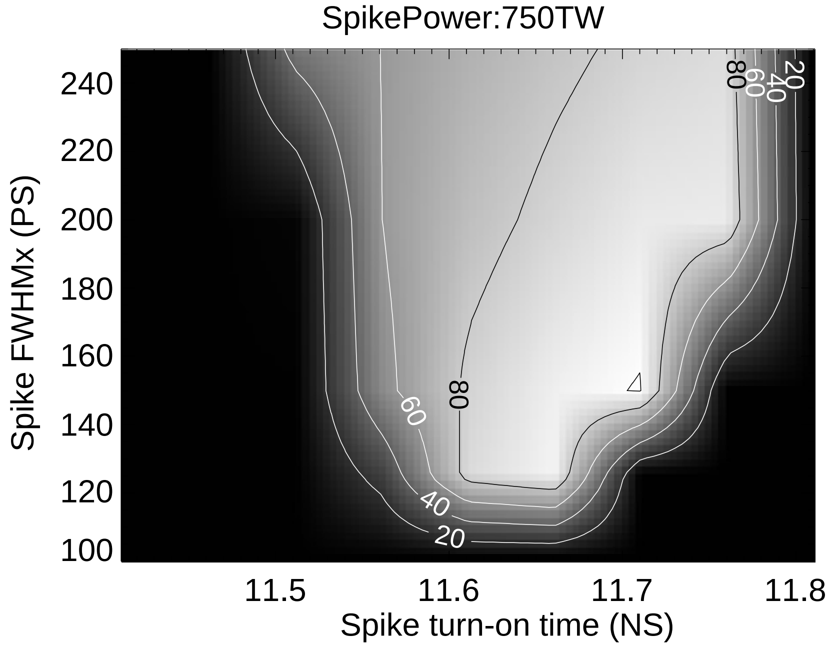
1D design work for E_{laser}~300kJ shows the sensitivity to spike parameters.

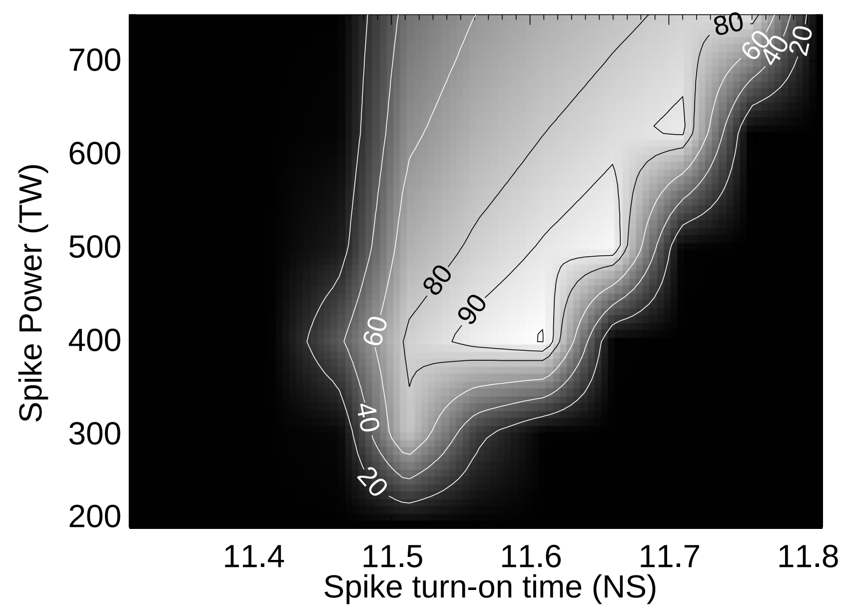
Target is thick (aspect ratio ~2) and driven to low velocity (2.5×10^7cm/s) before spike, so it should be more stable.



200-300 kJ SI target



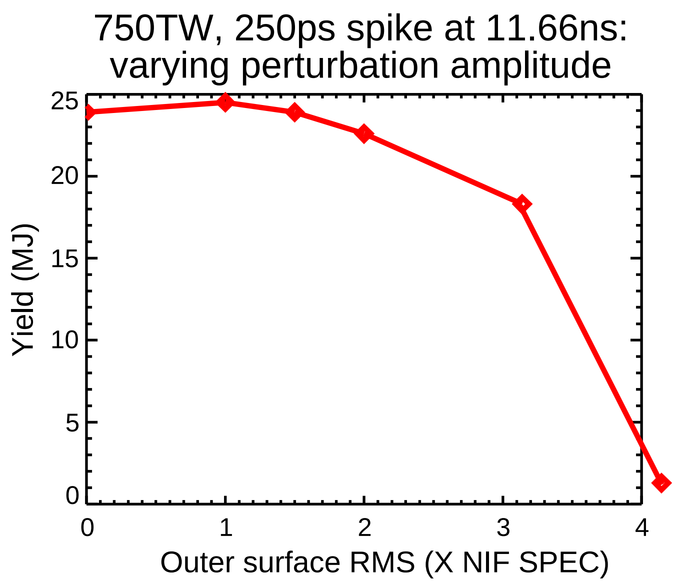


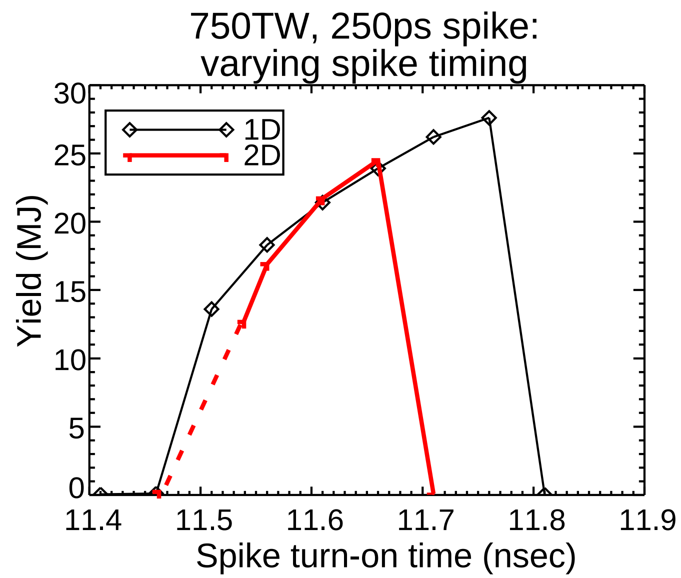


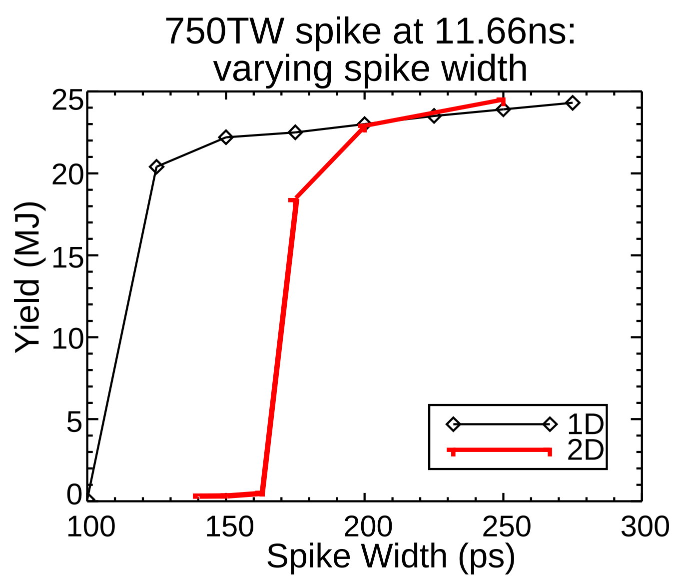
SI

Shock Ignition studies: ~300 kJ KrF pulse

2D low mode simulation results (64 θ pts, ℓ=2-16) indicate that this robustness survives in 2D.







Summary

We have investigated FTF and shock-ignition target designs with low- and high-resolution 2D simulations. Both laser and target surface perturbations have been simulated.

FTF-type targets can survive perturbations of order “NIF-spec.” with useful yields. Stabilization of higher frequency (ℓ>100) modes is possible with adiabat tailoring techniques, and performance appears to be dominated by low-modes. Outer surface finishes may be marginal, but 3D simulations are needed to resolve this.

Shock ignition designs promise higher gains and better stability. Our 1D and low-mode 2D studies look good so far, but high-resolution studies (underway) are needed.