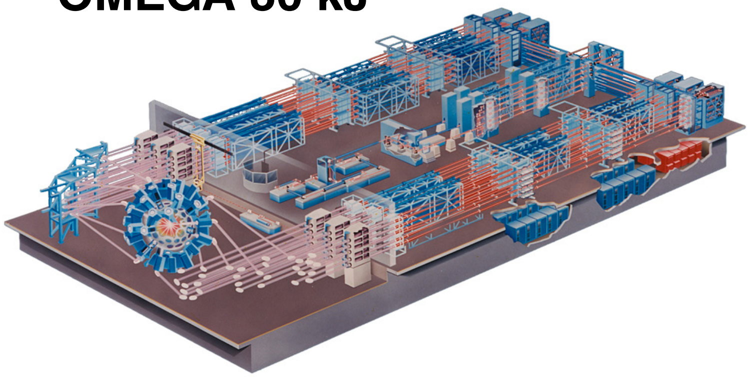
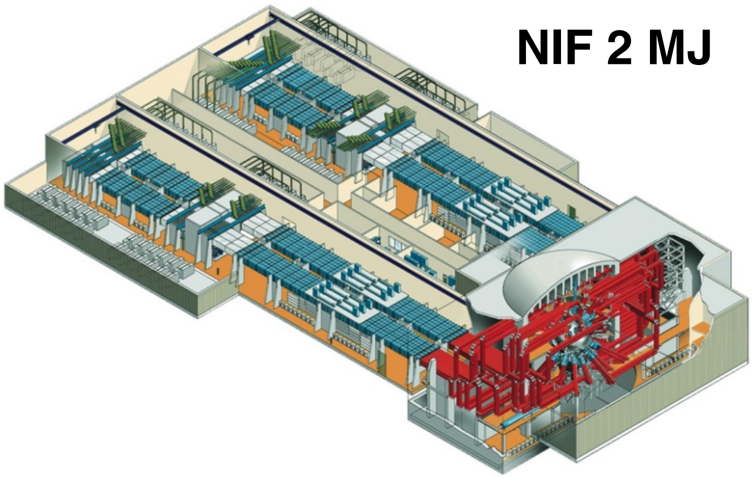
Achieving Record Fusion Yields in Direct-Drive Laser-Fusion Experiments Using Statistical Mapping

OMEGA 30 kJ



NIF 2 MJ



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Pathways and Progress Toward Fusion Power
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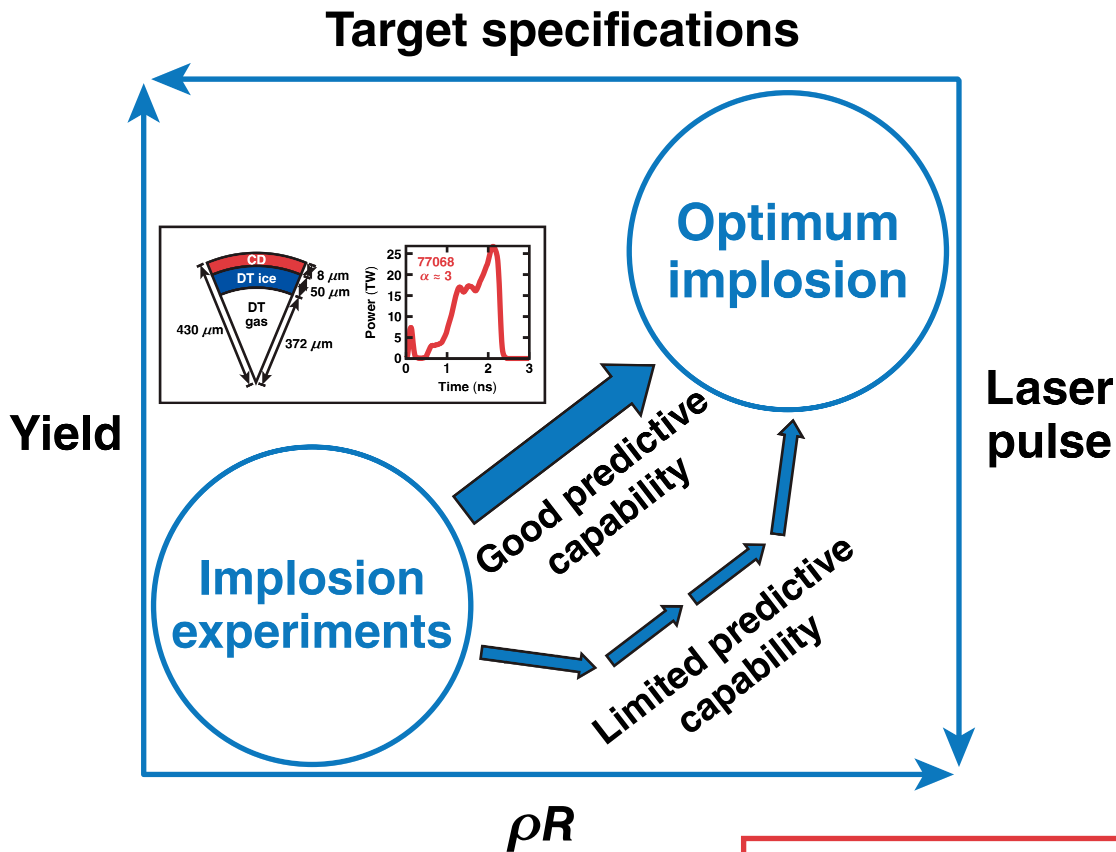
University of Rochester
Laboratory for Laser Energetics

A reliable predictive capability is required to find the optimum implosion



Lawson ignition parameter*
$\chi \sim \rho R^{2/3}$ yield$^{1/3}$

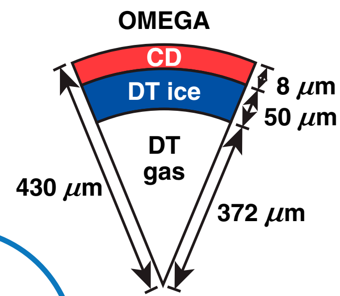
*R. Betti *et al.*, Phys. Plasmas 17, 058102 (2010);
B. K. Spears *et al.*, Phys. Plasmas 19, 056316 (2012).

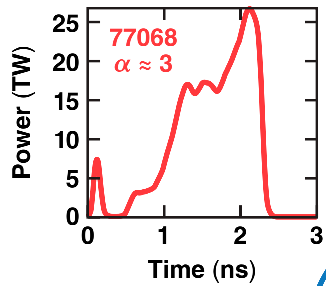
TC13679b

How can we predict the outcome of an implosion experiment? Find correlations to bridge the gap between simulations and experiments

UR LLE

Laser pulse and target specifications are inputs to both the code and the experiment





1-D physics models (*LILAC)**

Implosion experiment: real physics

Code output:

Yield^{LILAC}, V_{imp}^{LILAC}, ρR^{LILAC}, T_{i}^{LILAC}, τ^{LILAC}, R^{LILAC}

Mapping

Measurable parameters:

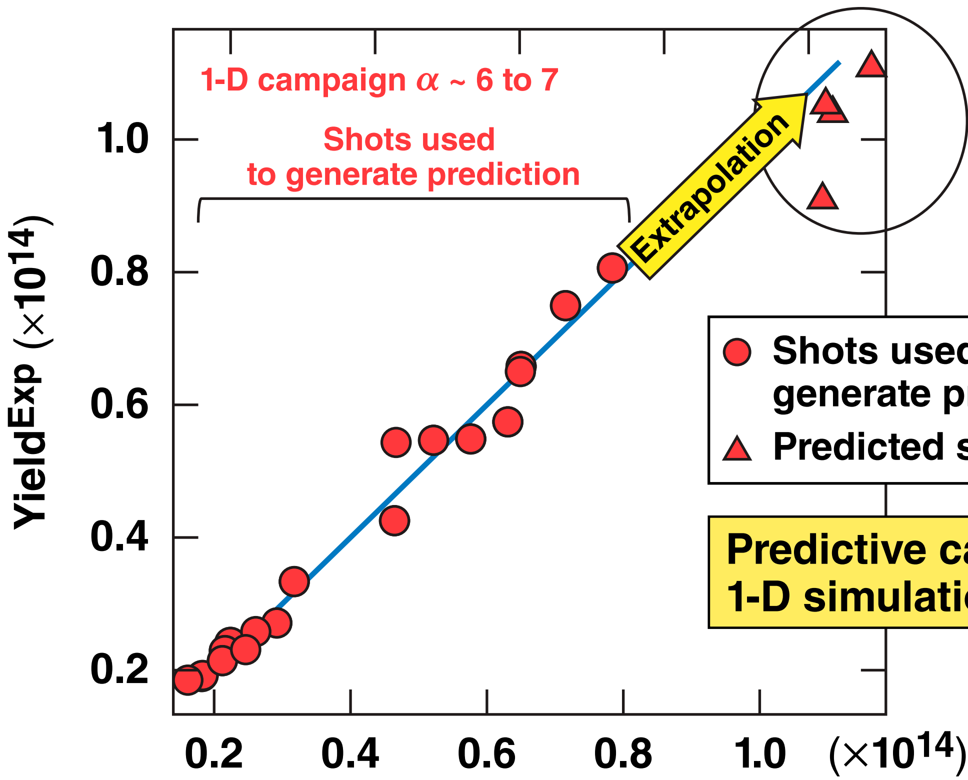
$\mathrm{Yield}^{\mathrm{Exp}}$, $V_{\mathrm{imp}}^{\mathrm{Exp}}$, ρR^{Exp}, $T_{\mathrm{i}}^{\mathrm{Exp}}$, τ^{Exp}, R^{Exp}

Example: $\mathrm{Yield}^{\mathrm{Exp}} = \mathrm{F}\left(V_{\mathrm{imp}}^{LILAC}, \rho R^{LILAC}, T_{\mathrm{i}}^{LILAC}, \tau^{LILAC} \ldots\right)$

*1-D hydrodynamic code

TC13680e

The combination of 1-D simulations and mapping relations provides a predictive capability as long as its validity can be extrapolated



Predictive capability:
1-D simulations + mapping relations

V_{imp}^{LILAC} = *LILAC* implosion velocity

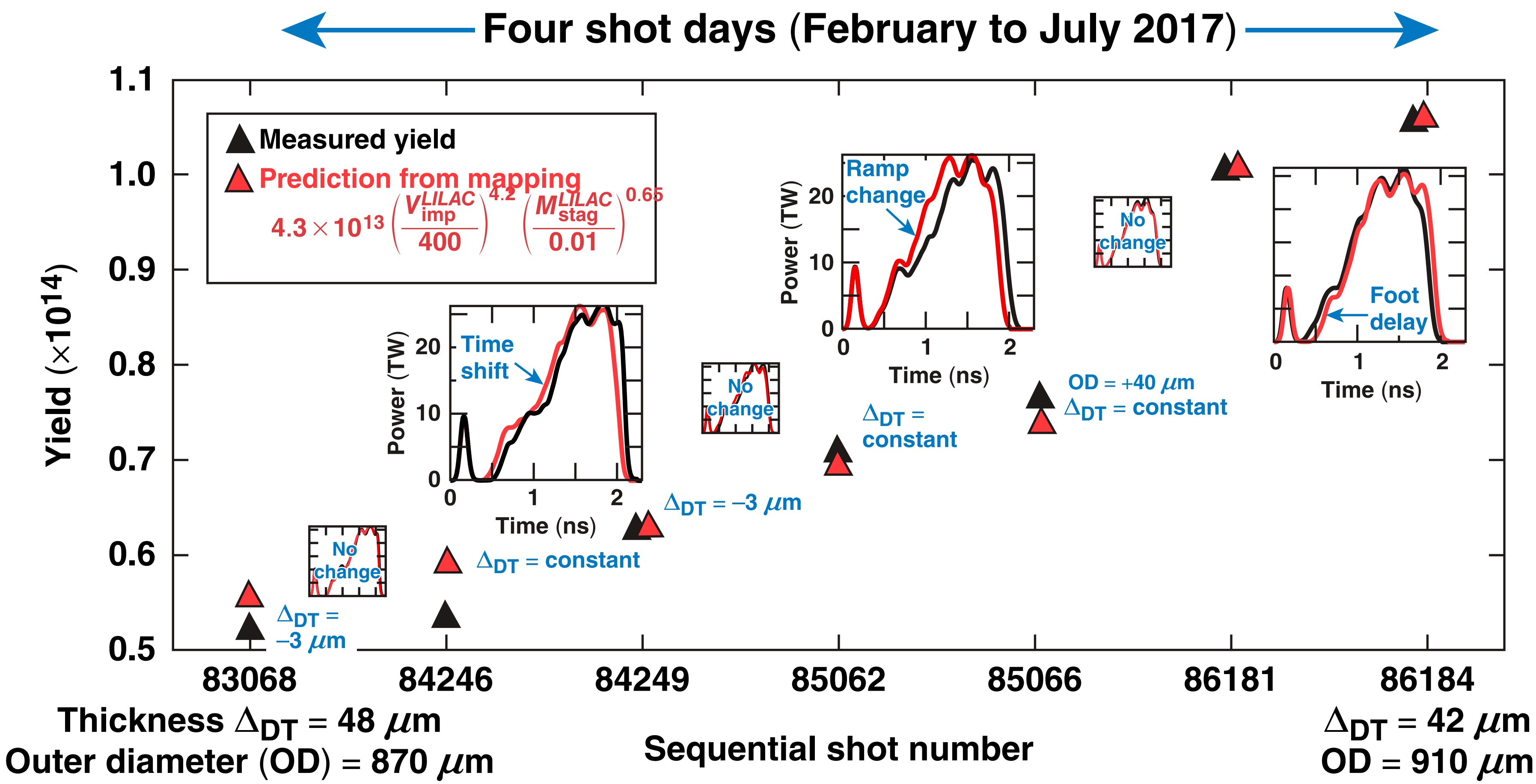
M_{stag}^{LILAC} = *LILAC* stagnating mass

Mapping onto 1-D simulated parameters →

$$4.3 \times 10^{13} \left(\frac{V_{imp}^{LILAC}}{400}\right)^{4.17} \left(\frac{M_{stag}^{LILAC}}{0.01}\right)^{0.65}$$

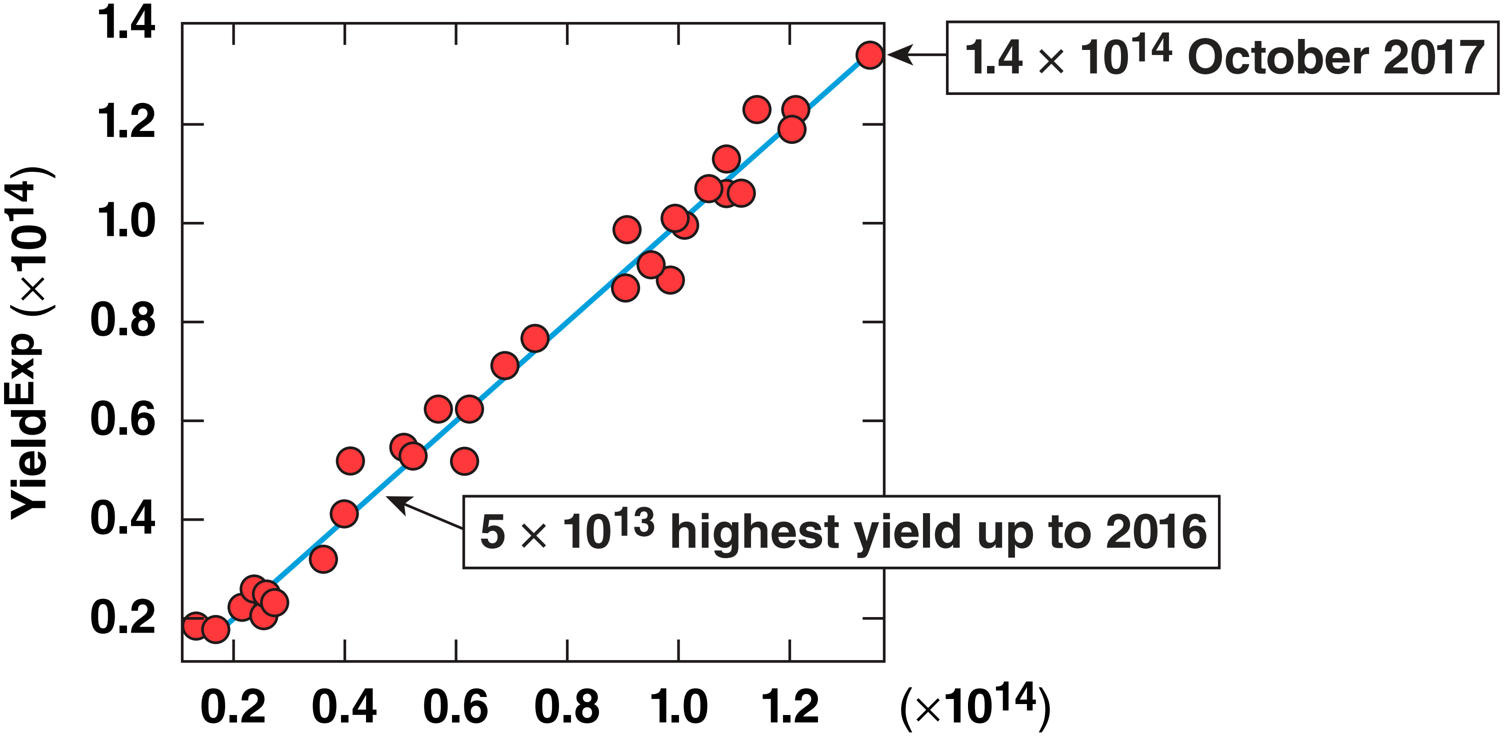
TC13681

Systematic changes to the target specifications and laser pulse resulted in the expected increase in yield



TC13688c

Designing new implosions using statistical mapping from previous implosions led to tripling the number of fusion reactions on the OMEGA laser

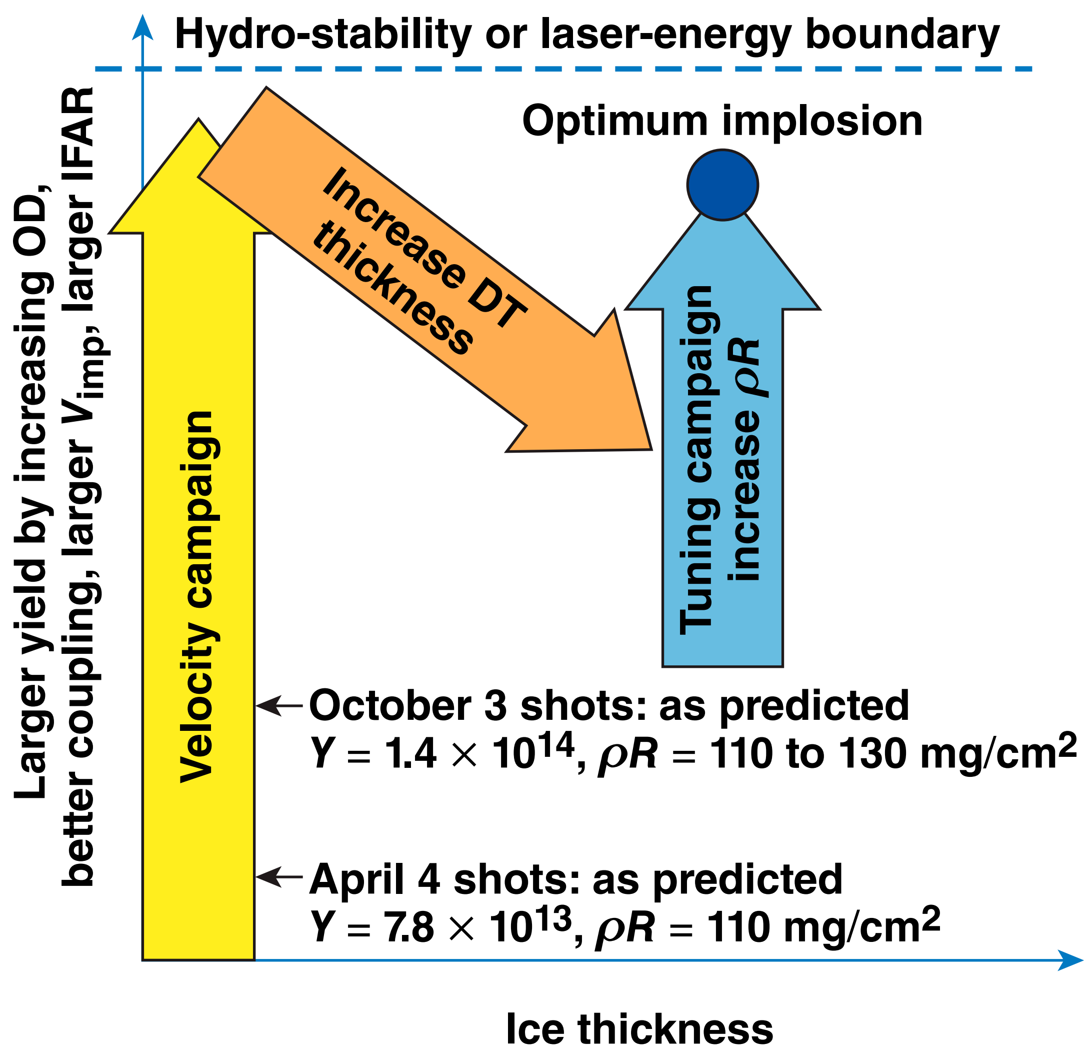


$$\left(V_{\text{imp}}^{LILAC}\right)^{4.3}\left(M_{\text{stag}}^{LILAC}\right)\left(\rho R^{LILAC}\right)^{0.3}\text{OD}_{\text{out}}^{-1.2}\left(\frac{T_{\text{min}}}{T_{\text{max}}}\right)$$

Most-accurate mapping relation

TC14002a

A systematic approach is used to find the optimum implosion on OMEGA

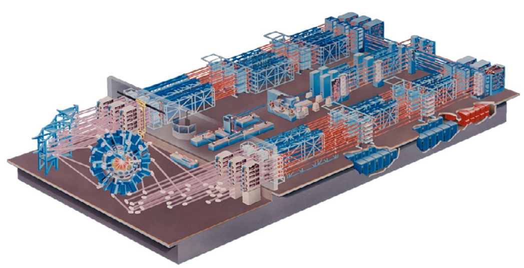


TC13691b

Hydrodynamic equivalence provides a tool to scale the performance of OMEGA direct-drive implosions to NIF energies

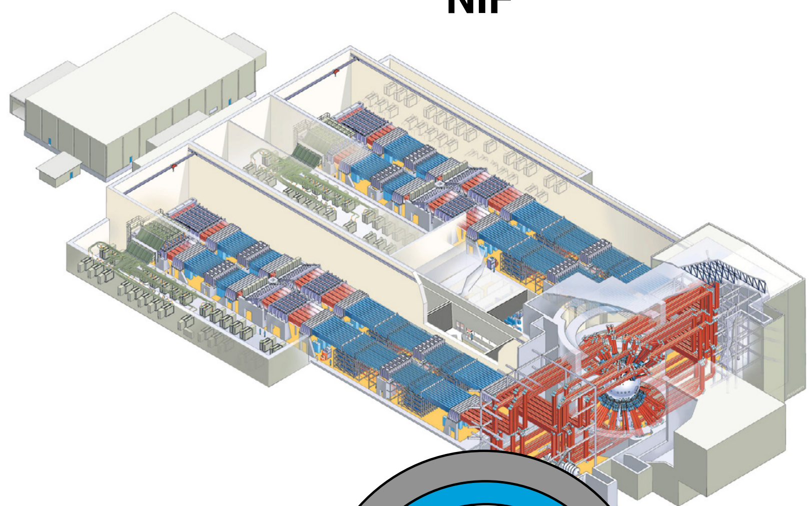
UR LLE

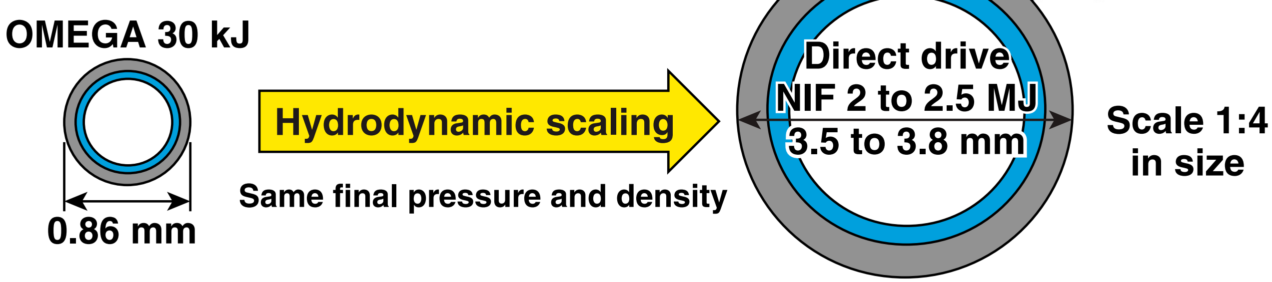
OMEGA



Scale 1:60
in energy

NIF



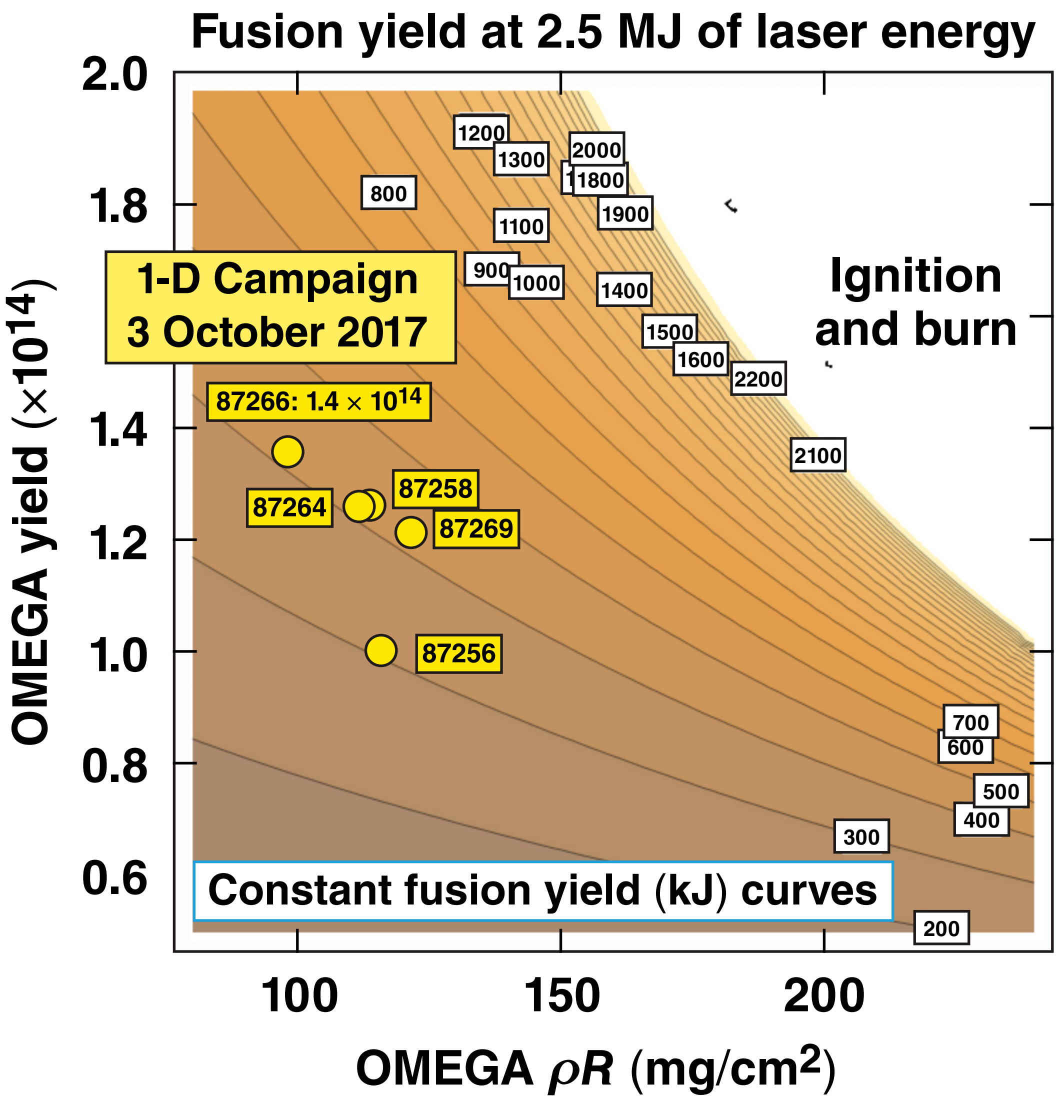


Volume ~ Mass ~ Laser energy

Scaled hydro-equivalent experiments are carried out on OMEGA.

TC12300e

The latest OMEGA implosions would produce 400 kJ of fusion energy when scaled to the NIF laser drive

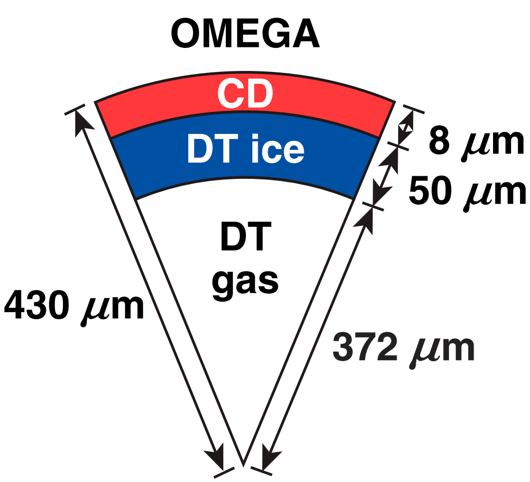


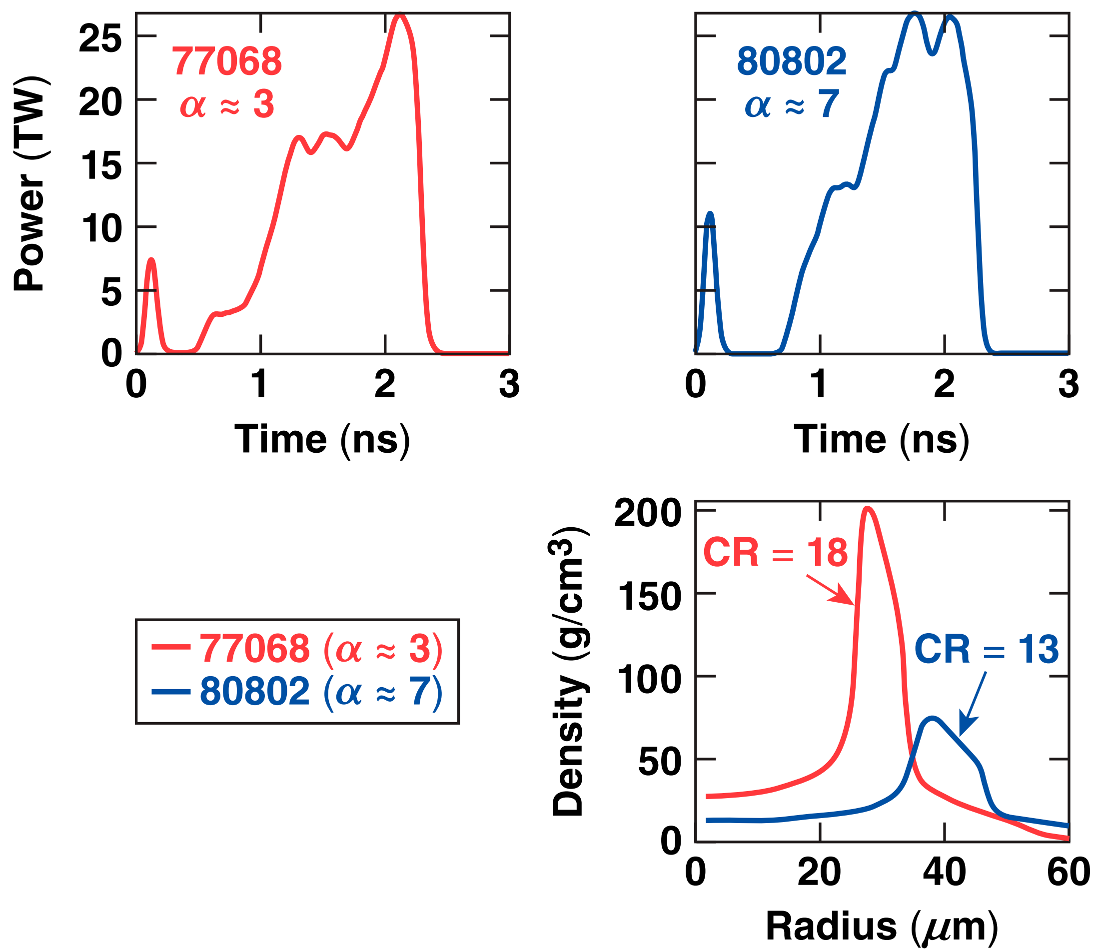
TC13995a

The recent results from OMEGA are exciting and give hope of rapid progress in laser fusion

- By mapping the experimental results onto the simulation database, an accurate predictive capability is developed
- This new predictive capability was used to design better implosions on the OMEGA laser
- The highest fusion yield (tripled in the past year) of 1.4×10^{14} was achieved by increasing the target outer diameter, reducing the DT ice thickness, and adjusting the laser pulse shape

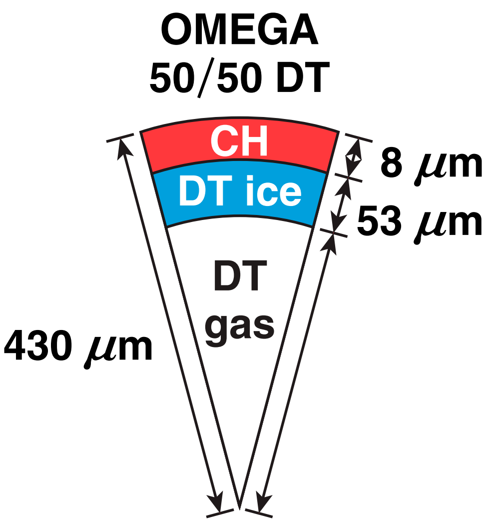
The 1-D Campaign developed a database of more-predictable, lower-convergence, high-adiabat implosions



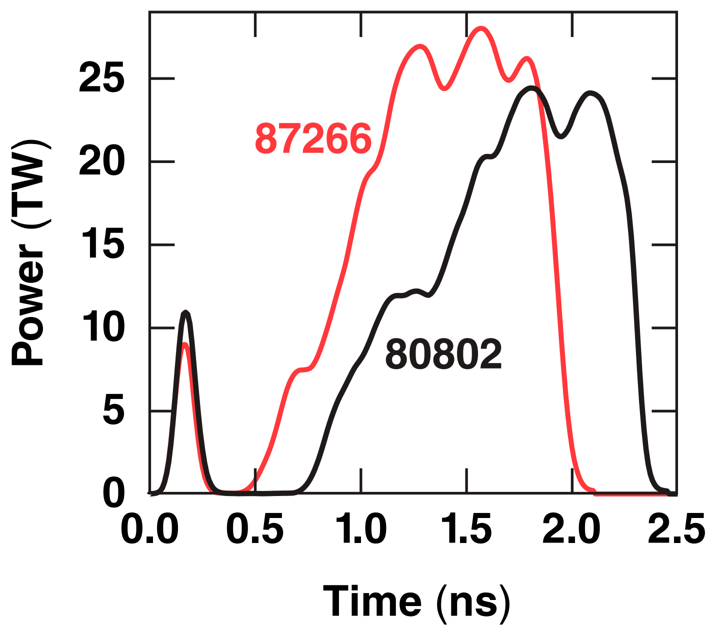


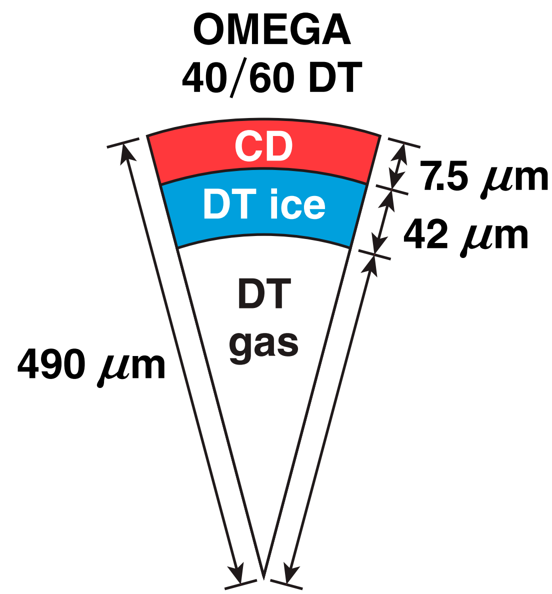
TC13096d

Higher yields were achieved through CD ablators, thinner ice, 40/60 DT mixture, modified pulse shapes, and larger-diameter shells



Shot 80802
Y = 3.2 × 10^{13}
ρR = 126 mg/cm^2
T_i = 2.6 keV





Shot 87258–69
Y = 1.2 to 1.4 × 10^{14}
ρR = 100 to 130 mg/cm^2
T_i = 4.3 to 4.6 keV

TC13687e