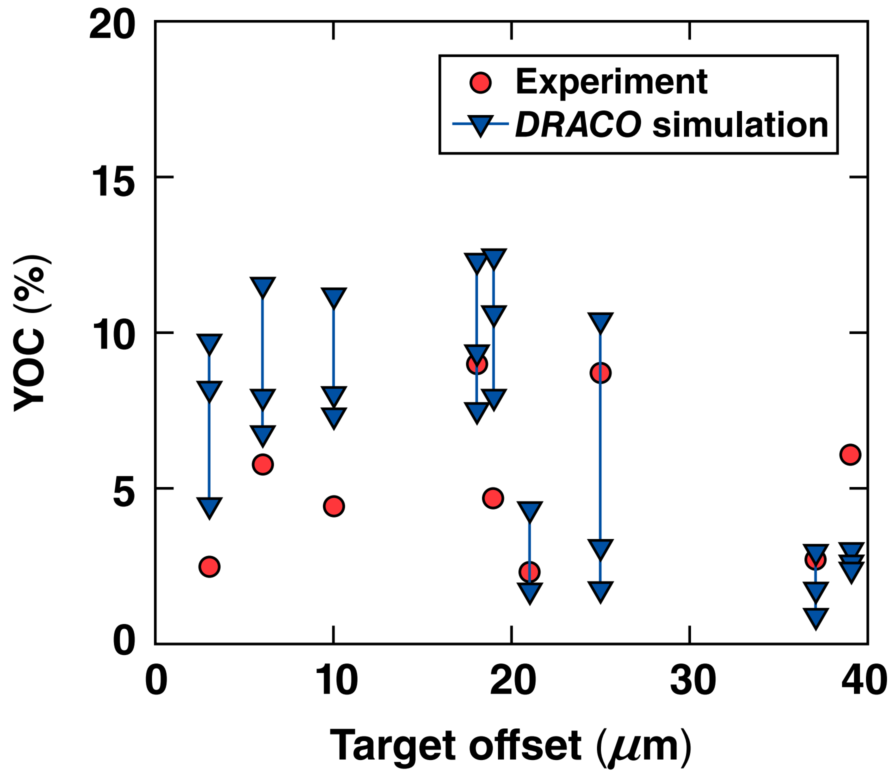
Two-Dimensional Radiation–Hydrodynamic Simulations of Cryogenic-DT Implosions at the Omega Laser Facility



S. X. Hu
University of Rochester
Laboratory for Laser Energetics

40th Annual Anomalous Absorption Conference
Snowmass Village, CO
13–18 June 2010

Summary

Dominant nonuniformity sources have been identified for improving neutron yield in cryogenic-DT implosions

- Cryogenic-DT implosions on OMEGA have reached high compressions with $\langle \rho R \rangle \sim 300\ \mathrm{mg/cm^2}$, but the yield-over-clean (YOC) for neutron production is only on the level of ~5%.
- Two-dimensional *DRACO* simulations reproduce well the YOC and ion temperature observed *in experiments*.
- To increase YOC to the ignition hydro-equivalent level of ~15% to 20%, the target offset must be ≤10 μm and smoothing by spectral dispersion (SSD) must be employed.

Collaborators

V. N. Goncharov, P. B. Radha, J. A. Marozas, S. Skupsky, T. R. Boehly,
T. C. Sangster, D. D. Meyerhofer, and R. L. McCrory

Laboratory for Laser Energetics
University of Rochester

Hydro-simulations are essential in identifying nonuniformities for increasing YOC to the ignition hydro-equivalent level

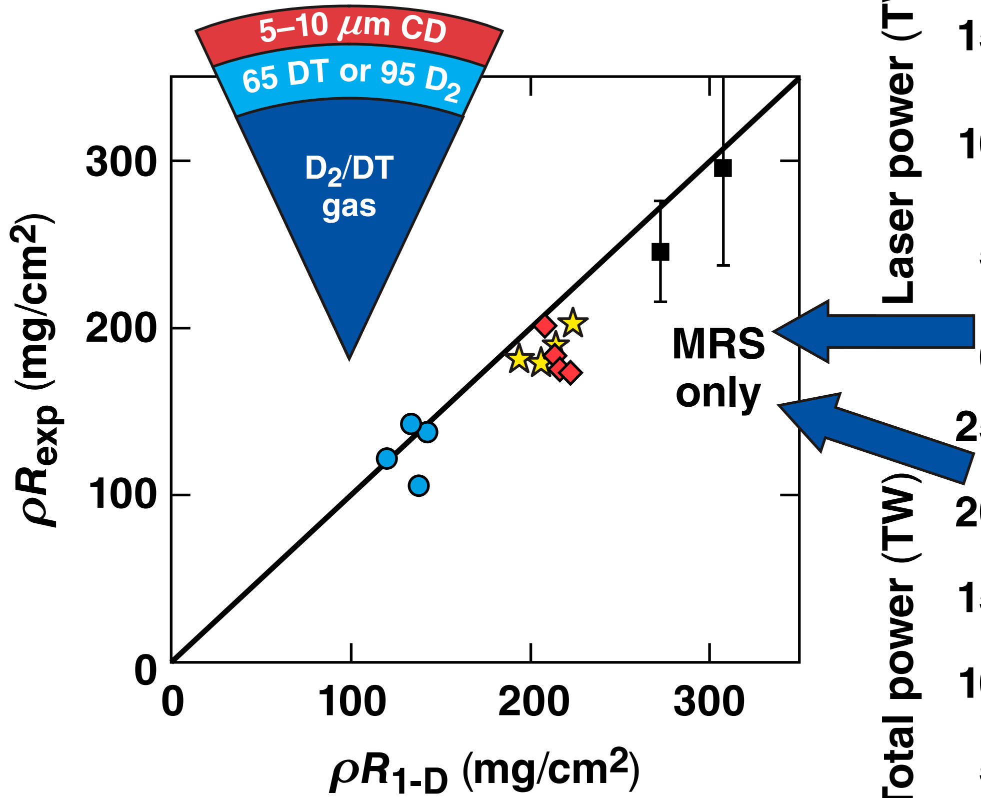
UR LLE

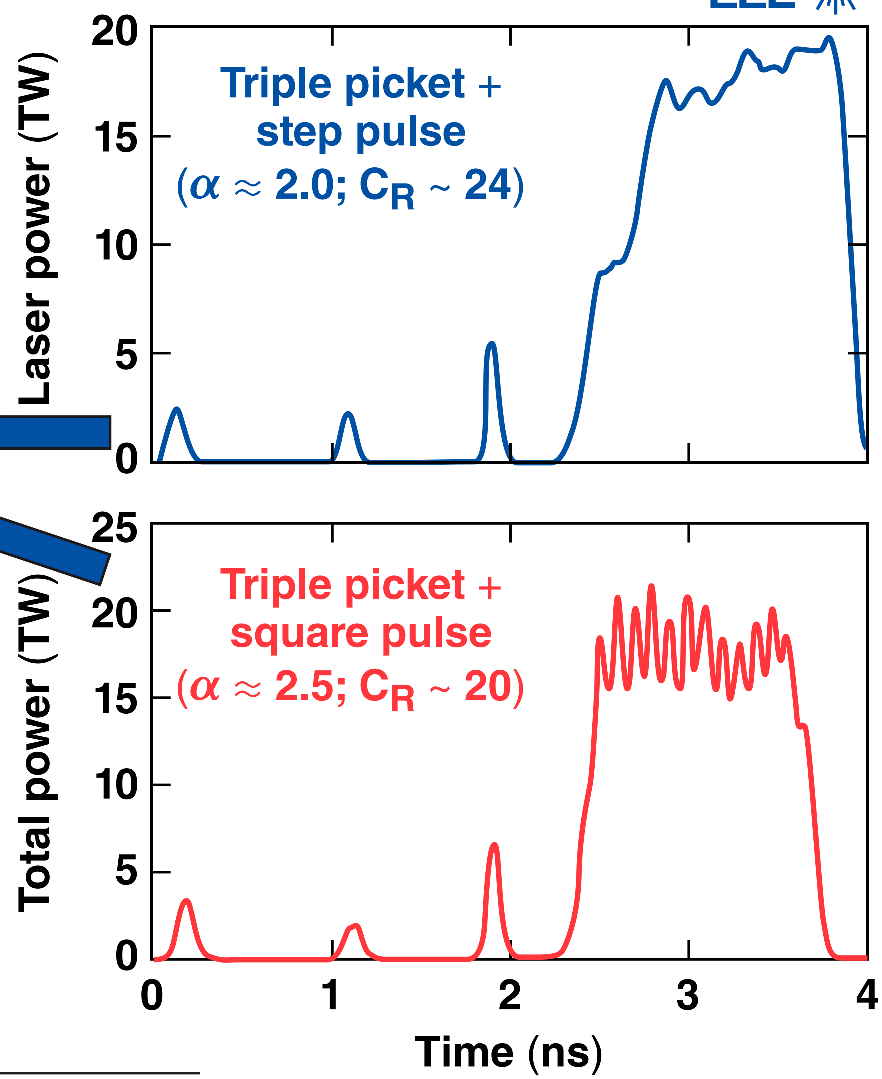
- For hot-spot-ignition designs*, there is a minimum requirement on the neutron yield-over-clean (YOC ~ 50%) on the NIF, in addition to the successful assembly of a high-density shell (ρR).
- The ignition hydro-equivalent of cryogenic DT implosions on OMEGA require a YOC level of ~15% to 20%.
- High compression with $\langle \rho R \rangle$ ~ 300 mg/cm^2 has been achieved on OMEGA**, while the neutron yield is on the level of YOC ~ 5%.
- Two-dimensional *DRACO* simulations identify the major perturbation sources for improving the current YOC to the ignition hydro-equivalent level.

*T. Collins (invited talk, this morning)
**V. N. Goncharov *et al*., Phys. Rev. Lett. 104, 165001 (2010); T. C. Sangster *et al*., Phys. Plasmas 17, 056312 (2010).

TC8831

Cryogenic-DT implosions have achieved high compression ($\langle \rho R \rangle \gtrsim 300$ mg/cm^2) on OMEGA





Target and laser perturbations result in an YOC level of ~5% for these implosions.

TC8833

*V. N. Goncharov *et al*., Phys. Rev. Lett. 104, 165001 (2010); T. C. Sangster *et al*., Phys. Plasmas 17, 056312 (2010).

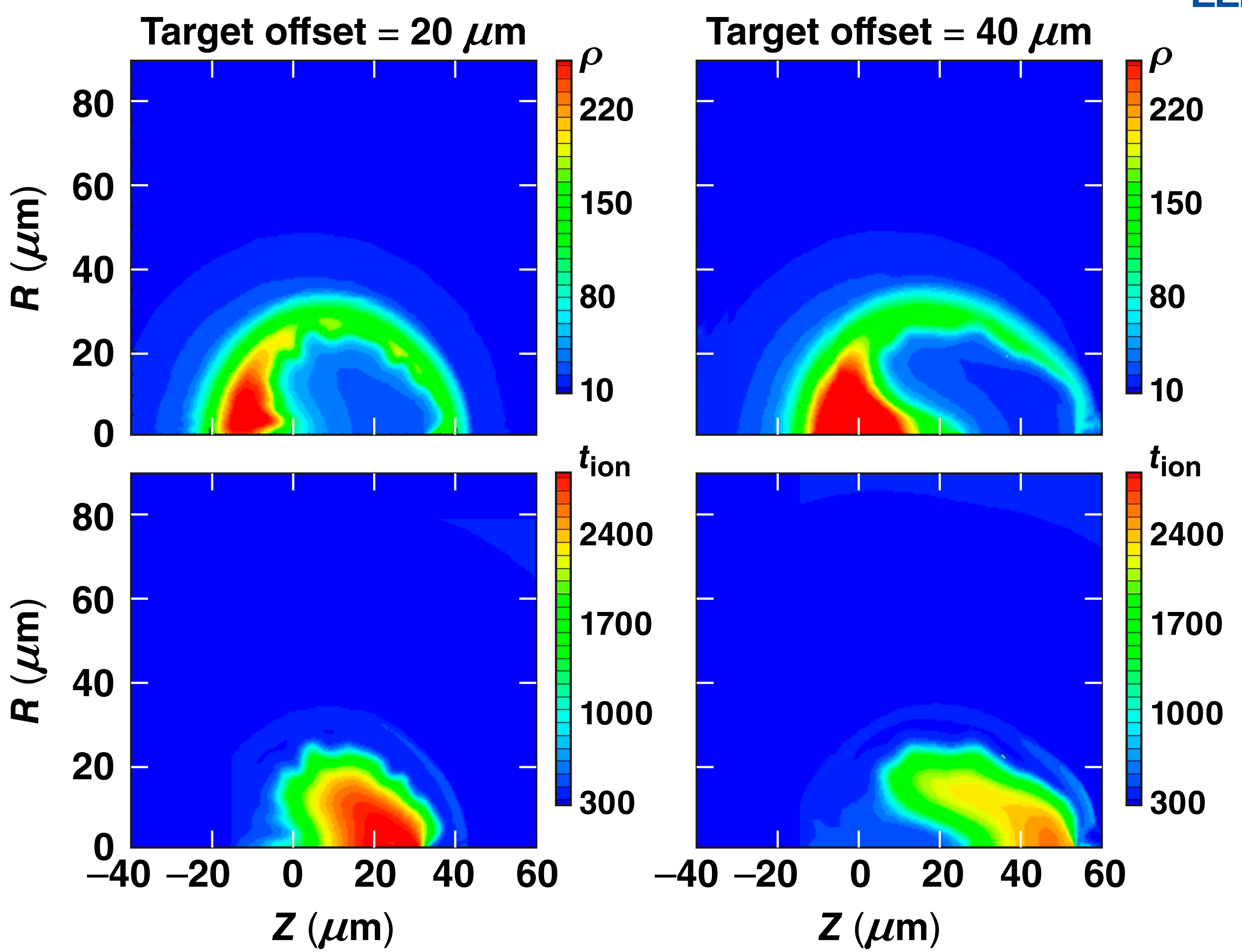
Target and laser perturbations reduce the neutron yield in cryogenic-DT implosions on OMEGA

- Target perturbations
  - offset from the target chamber center
  - ice roughness at inner surface
- Laser nonuniformities
  - low-mode beam-to-beam nonuniformities (mistiming, mispointing, power imbalance)
  - Single-beam nonuniformity (laser imprinting)

Low-mode laser nonuniformities on OMEGA reduce YOC only by 7% ~ 15%

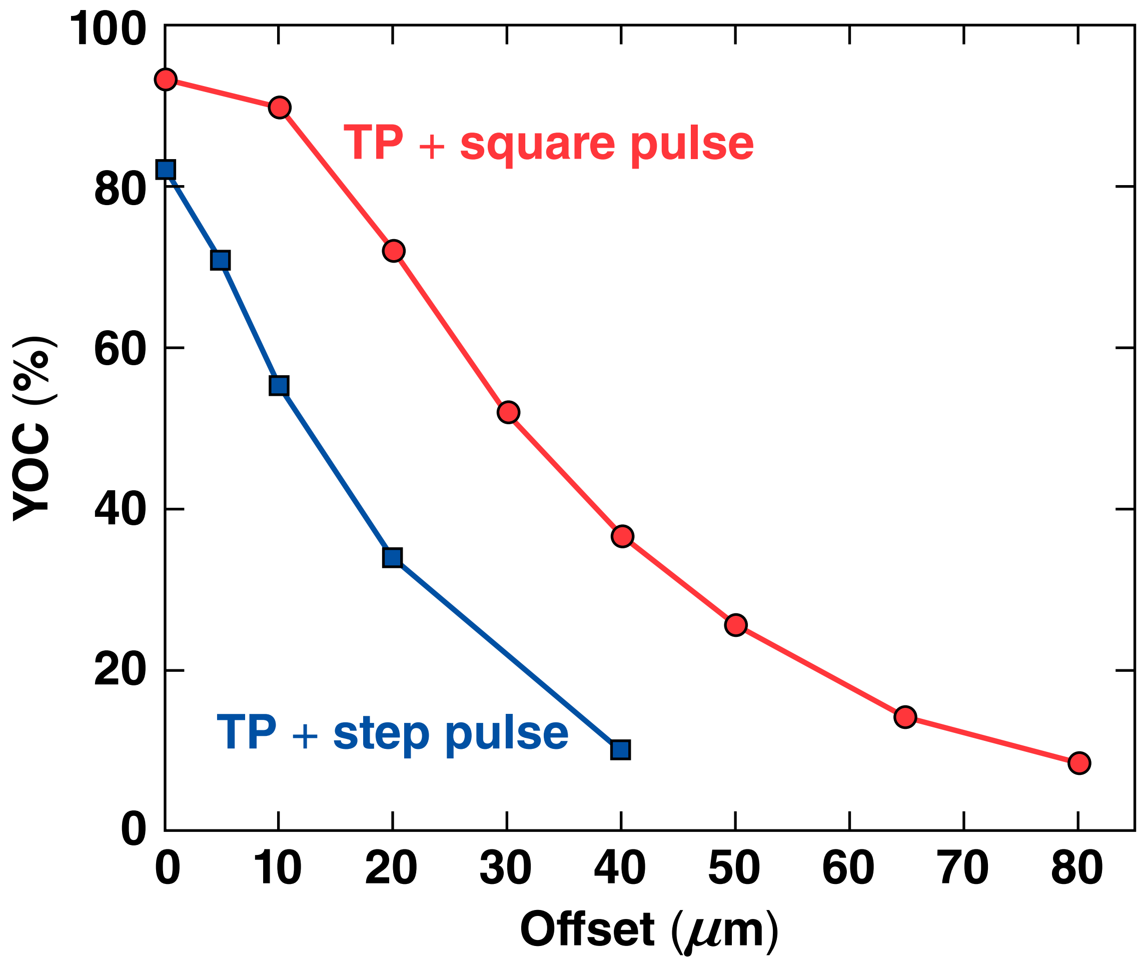
Typical laser-beam perturbations on OMEGA	YOC (square pulse)	YOC (step pulse)
Mistiming (σ_{rms} ~ 9 ps)	94.1%	92.2%
Static mispointing (σ_{rms} ~ 10 μm)	93.8%	91.9%
Power imbalance (σ_{rms} ~3% overall)	93.6%	92.9%
All above perturbations together	93.4%	83.3%

Target offset imposes a dominant $\ell = 1$ perturbation to cause the asymmetry in implosions



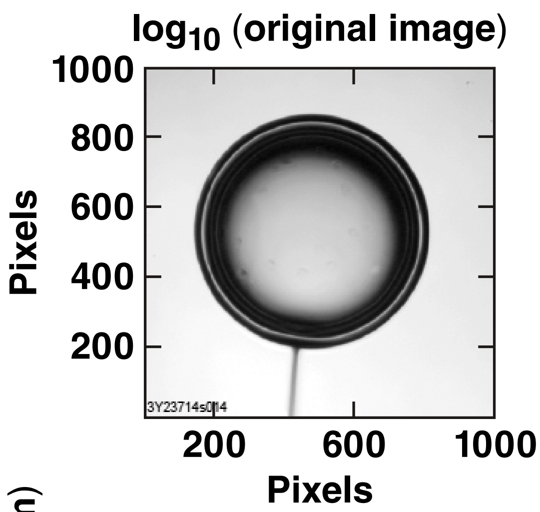
TC8839

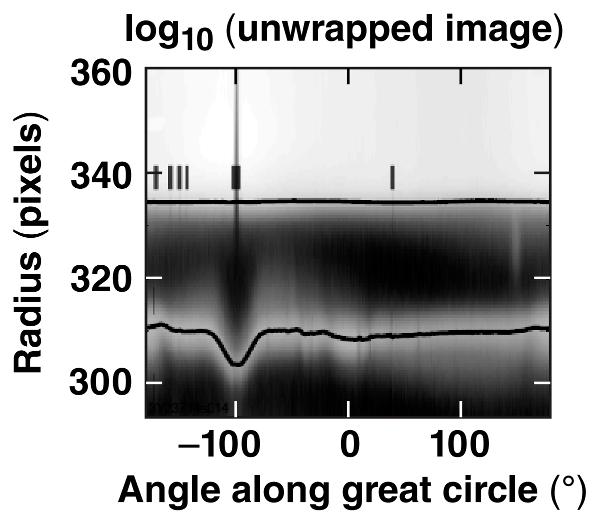
Target offsets larger than ~20-μm significantly reduce YOC for step-pulse designs

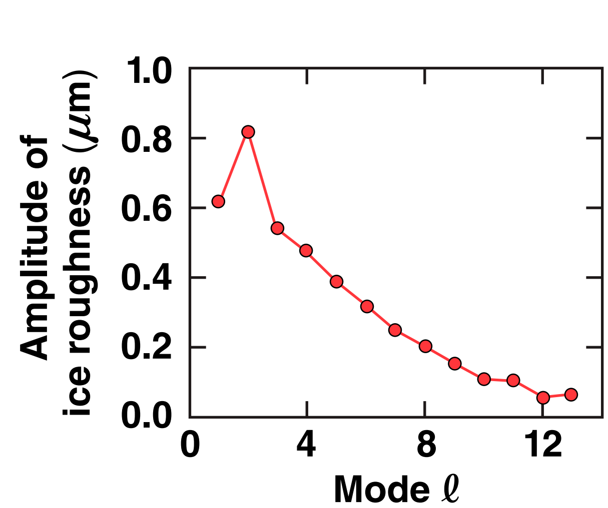


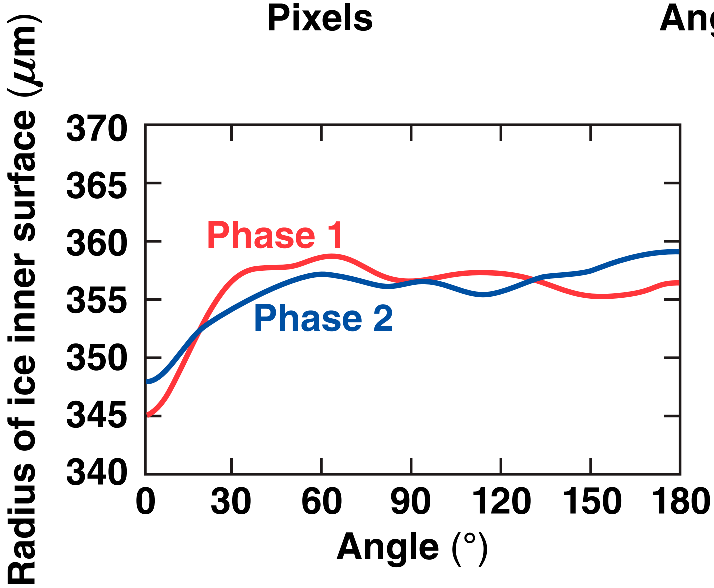
TC8803

Ice-layer-roughness effects can be simulated by using the measured spectrum







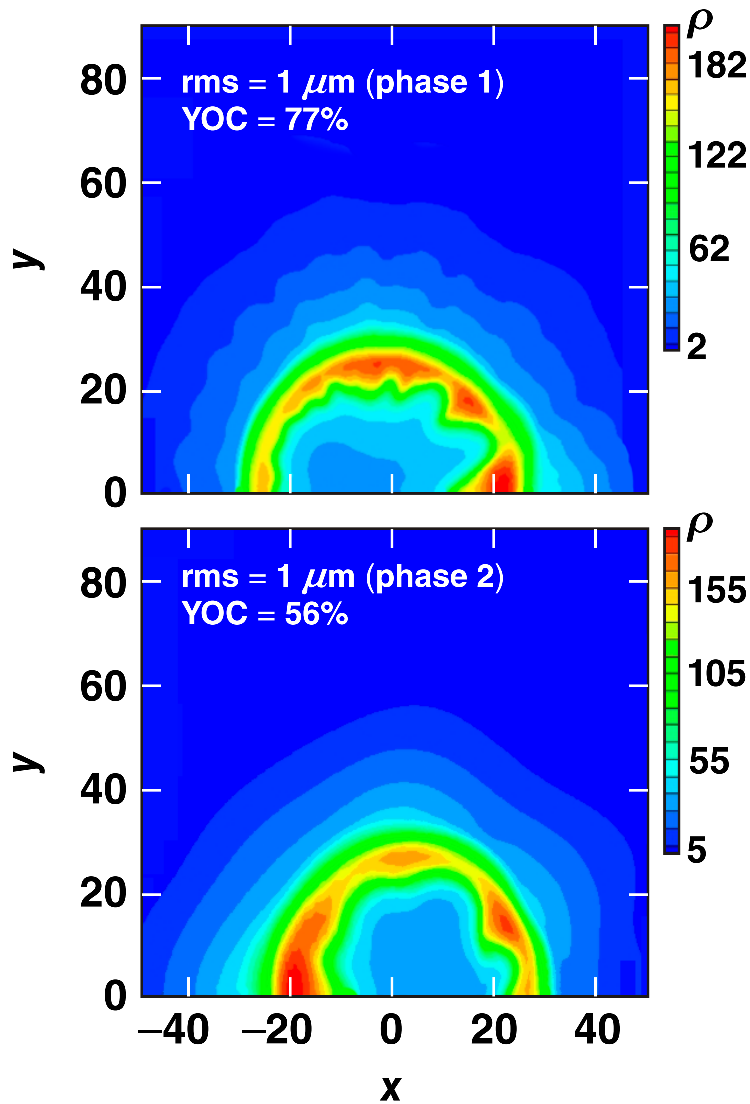


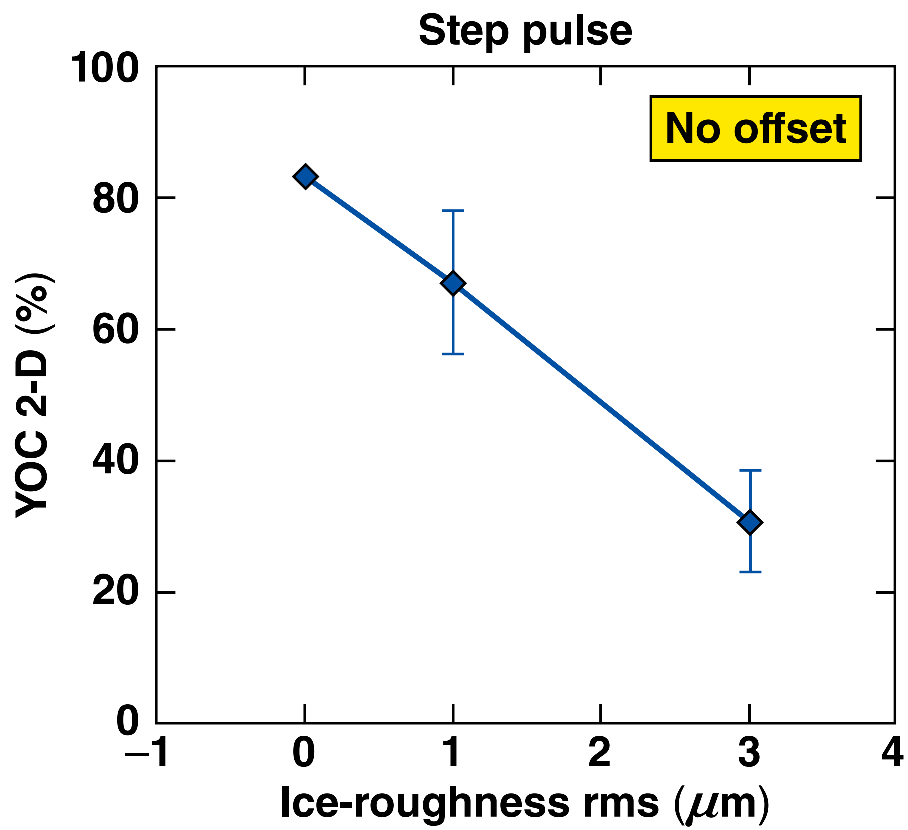
$$\Delta R(\theta) = \Delta R_0 + \sum_{\ell=1}^{n} \pm A_\ell \cos(\ell\theta)$$

Different "phases" need to be explored.

TC8840

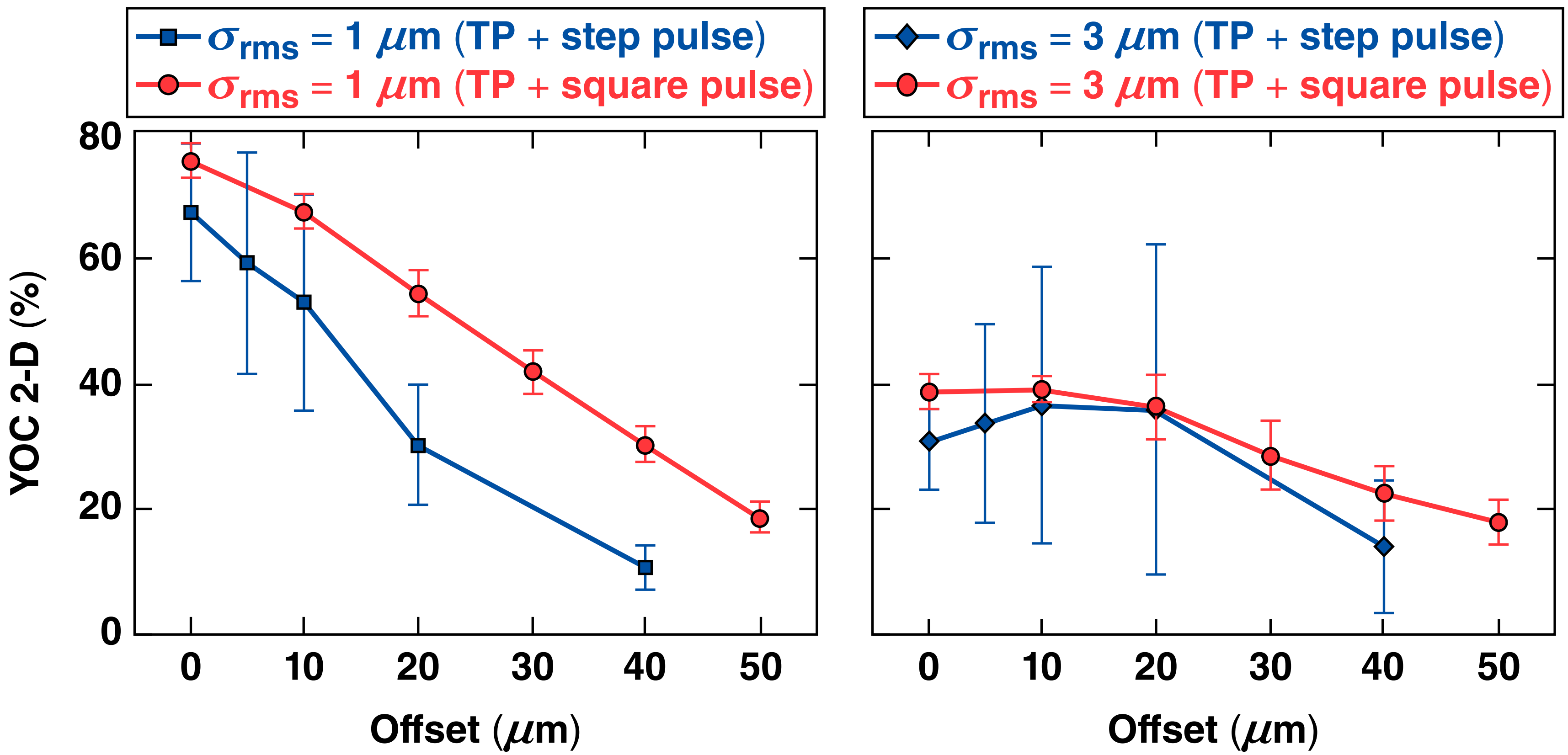
Ice roughness of cryogenic-DT target at σ_{rms} ~ 1 μm reduces the YOC to ~65%





TC8841

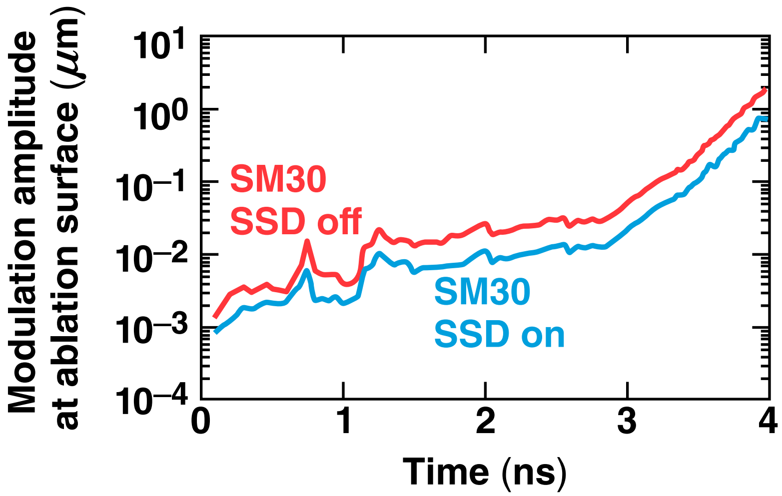
For the step-pulse design, target offset must be less than 10 μm to have a YOC > 50%

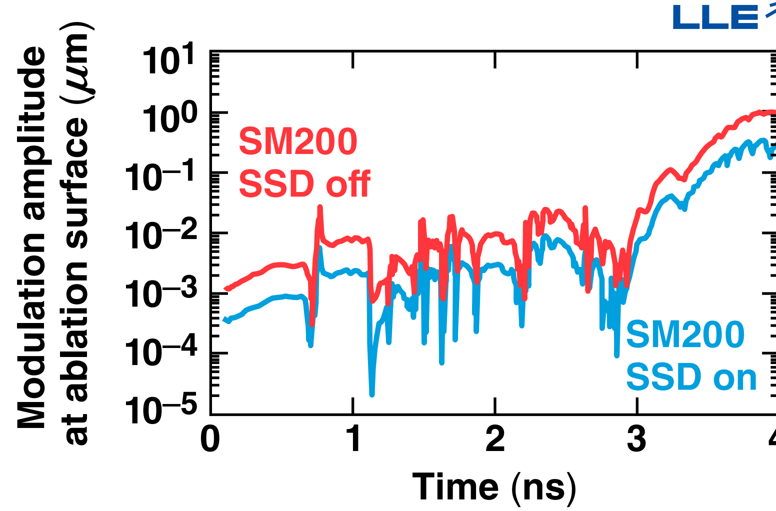


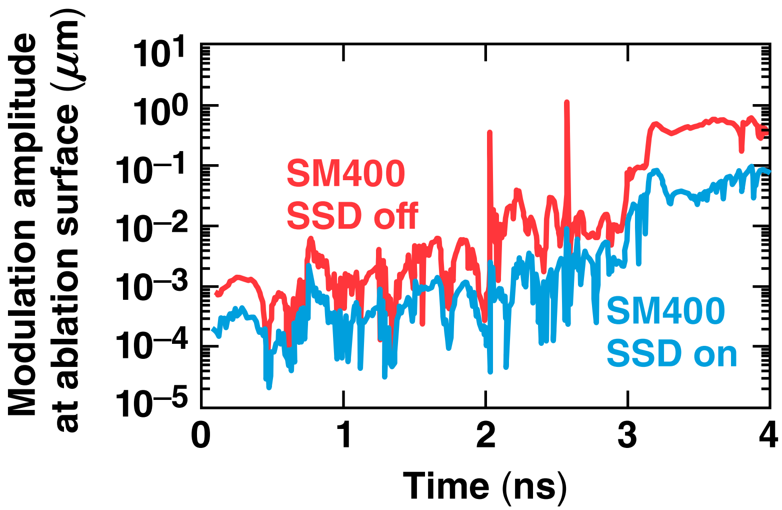
A good ice layer (σ_{rms} = 1 μm) can be achieved on OMEGA.

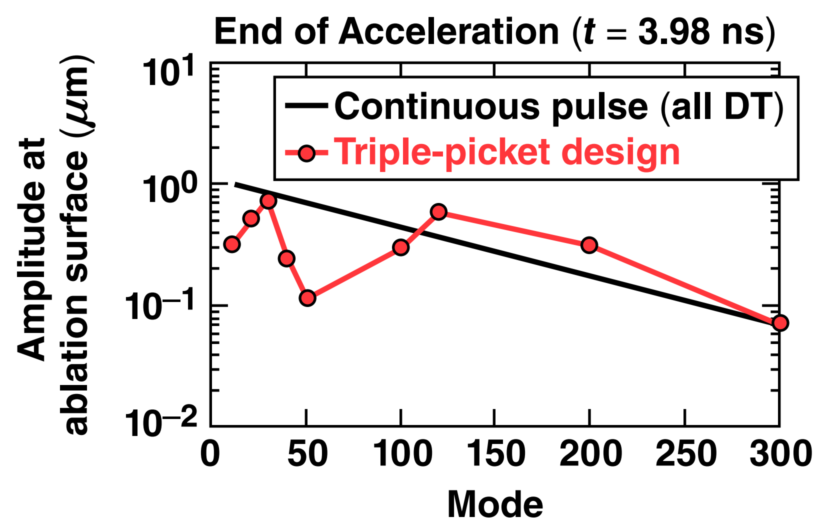
TC8842

Single-mode simulations of laser imprinting up to $\ell = 500$ have been performed for the step-pulse designs





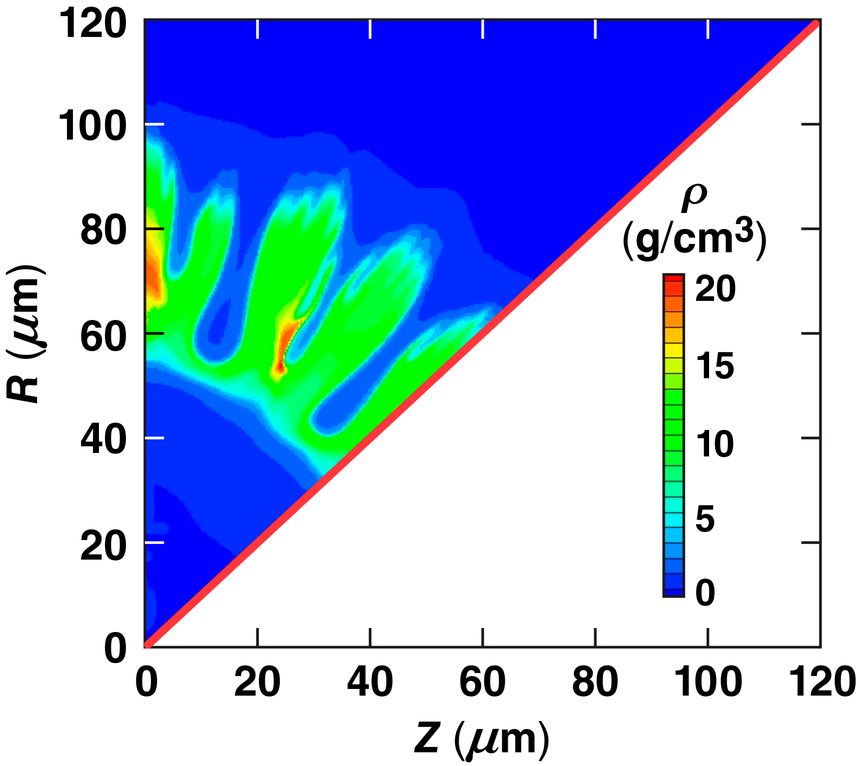


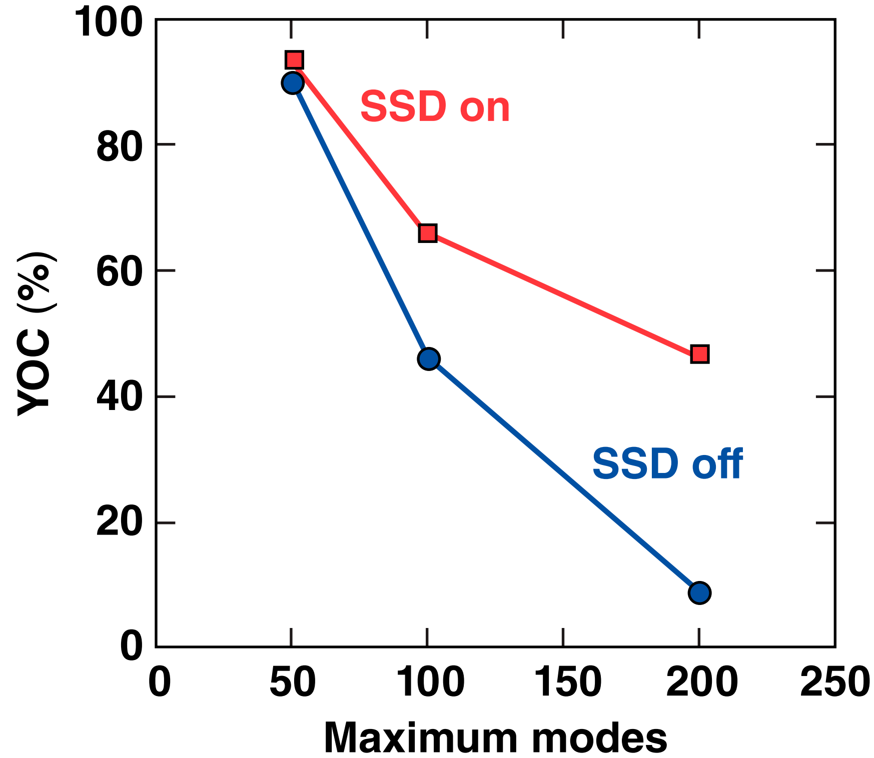


SSD (1-cc, 1-THz) smoothing reduces the perturbation amplitude by a factor of ~3 to 4.

TC8843

Laser imprinting is another important nonuniformity source for reducing YOC





Laser-imprinting effects:
SSD on: YOC ~ 50 %
SSD off: YOC ~ 25 %

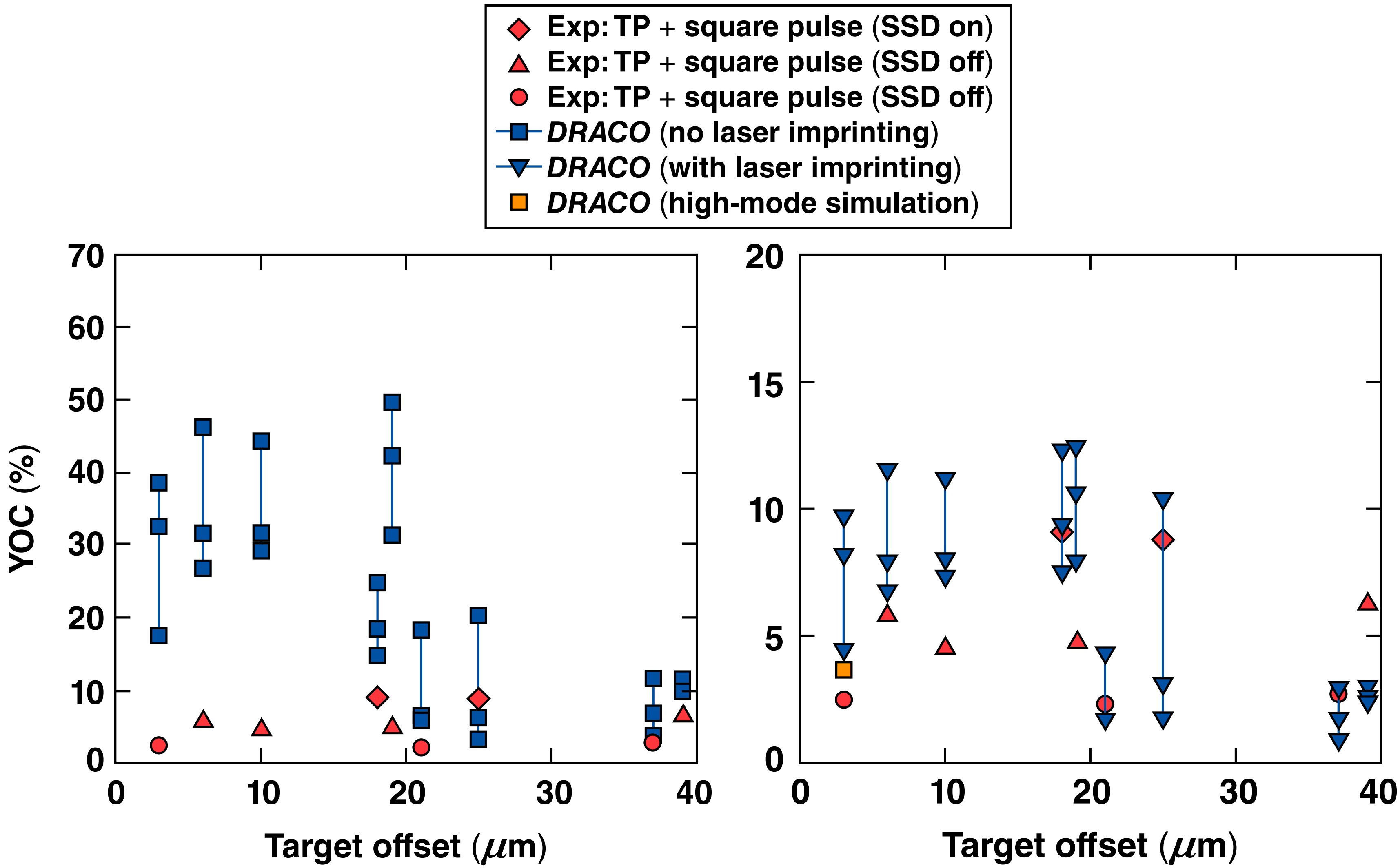
High modes (ℓ > 150) can be stabilized by nonlocal electron heating of the ablation surface.*

TC8844

*V. A. Smalyuk *et al*., Phys. Rev. Lett. 101, 025002 (2008).

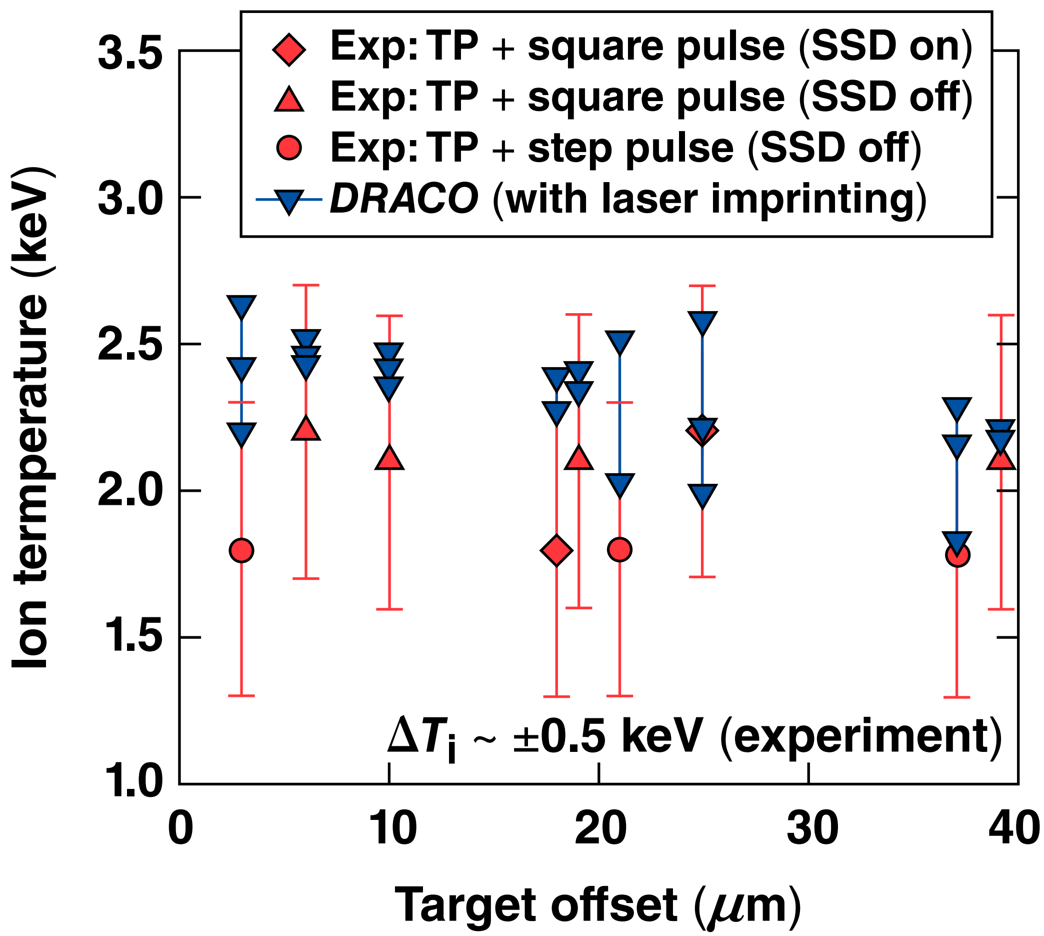
DRACO simulations for individual shots agree with experimental YOC within a factor of ~2 or better

UR LLE



TC8845

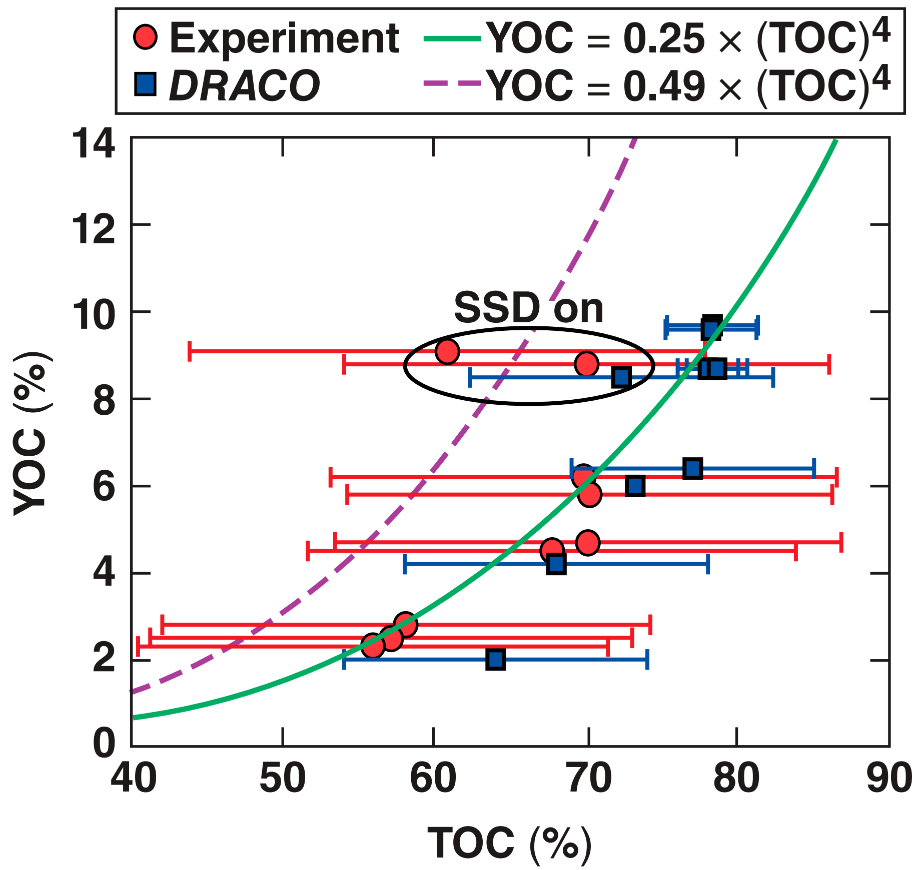
DRACO simulated $\langle T_i \rangle_n$ agree with the measured ion temperatures within the experimental uncertainty



The relation of YOC versus TOC indicates the distortion of the "hot spot"

UR LLE

Temperature-Over-Clean
$\mathrm{TOC} = \langle T_i \rangle_{exp/DRACO} / \langle T_i \rangle_{1\text{-}D}$



$$\mathrm{Yield} \sim V \times t_b \times \rho_{hs}^2 \times T_i^4$$

Divided by 1-D values

$$\mathrm{YOC} = \underbrace{\frac{\left(\sqrt{Vt_b}\,\rho_{hs}\right)^2}{\left(\sqrt{Vt_b}\,\rho_{hs}\right)^2_{1\text{-}D}}}_{\text{prefactor}} \times (\mathrm{TOC})^4$$

0.25

$$\left(\sqrt{Vt_b}\,\rho_{hs}\right) / \left(\sqrt{Vt_b}\,\rho_{hs}\right)_{1\text{-}D} \sim 50\%$$

TC8847

Summary/Conclusions

Dominant nonuniformity sources have been identified for improving neutron yield in cryogenic-DT implosions

- Cryogenic-DT implosions on OMEGA have reached high compressions with $\langle \rho R \rangle \sim 300$ mg/cm^2, but the yield-over-clean (YOC) for neutron production is only on the level of ~5%.
- Two-dimensional *DRACO* simulations reproduce well the YOC and ion temperature observed *in experiments*.
- To increase YOC to the ignition hydro-equivalent level of ~15% to 20%, the target offset must be ≤ 10 μm and smoothing by spectral dispersion (SSD) must be employed.