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

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

- Cryogenic-DT implosions on OMEGA have reached high compressions with $\langle \rho R \rangle \sim 300 \text{ mg/cm}^2$, but the yield-over-clean (YOC) for neutron production is only on the level of $\sim 5\%$.

- Two-dimensional DRACO simulations reproduce well the YOC and ion temperature observed in experiments.

- To increase YOC to the ignition hydro-equivalent level of $\sim 15\%$ to $20\%$, the target offset must be $\leq 10 \mu\text{m}$ and smoothing by spectral dispersion (SSD) must be employed.

Summary
Collaborators


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

- For hot-spot-ignition designs*, there is a minimum requirement on the neutron yield-over-clean (YOC \sim 50\%) on the NIF, in addition to the successful assembly of a high-density shell (\rho R).

- The ignition hydro-equivalent of cryogenic DT implosions on OMEGA require a YOC level of \sim 15\% to 20\%.

- High compression with \langle \rho R \rangle \sim 300 \text{ mg/cm}^2 has been achieved on OMEGA**, while the neutron yield is on the level of YOC \sim 5\%.

- Two-dimensional DRACO simulations identify the major perturbation sources for improving the current YOC to the ignition hydro-equivalent level.

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*T. Collins (invited talk, this morning)

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

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

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%

<table>
<thead>
<tr>
<th>Typical laser-beam perturbations on OMEGA</th>
<th>YOC (square pulse)</th>
<th>YOC (step pulse)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mistiming ($\sigma_{\text{rms}} \sim 9$ ps)</td>
<td>94.1%</td>
<td>92.2%</td>
</tr>
<tr>
<td>Static mispointing ($\sigma_{\text{rms}} \sim 10 \mu m$)</td>
<td>93.8%</td>
<td>91.9%</td>
</tr>
<tr>
<td>Power imbalance ($\sigma_{\text{rms}} \sim 3%$ overall)</td>
<td>93.6%</td>
<td>92.9%</td>
</tr>
<tr>
<td>All above perturbations together</td>
<td>93.4%</td>
<td>83.3%</td>
</tr>
</tbody>
</table>
Target offset imposes a dominant $\ell = 1$ perturbation to cause the asymmetry in implosions.
Target offsets larger than \(~20\-\mu m\) significantly reduce YOC for step-pulse designs.
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.
Ice roughness of cryogenic-DT target at $\sigma_{\text{rms}} \sim 1 \mu m$ reduces the YOC to $\sim 65\%$
For the step-pulse design, target offset must be less than 10 $\mu$m to have a YOC $> 50%$

A good ice layer ($\sigma_{\text{rms}} = 1 \mu$m) can be achieved on OMEGA.
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.
Laser imprinting is another important nonuniformity source for reducing YOC.

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

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

DRACO simulations for individual shots agree with experimental YOC within a factor of ~2 or better
DRACO simulated $\langle T_i \rangle_n$ agree with the measured ion temperatures within the experimental uncertainty.

$\Delta T_i \sim \pm 0.5$ keV (experiment)
The relation of YOC versus TOC indicates the distortion of the “hot spot”

\[
\text{TOC} = \langle T_i \rangle_{\text{exp/DRACO}} / \langle T_i \rangle_{1-D}
\]

\[
YOC = 0.25 \times (\text{TOC})^4
\]

\[
YOC = 0.49 \times (\text{TOC})^4
\]

\[
\text{Yield} \sim V \times t_b \times \rho_{hs}^2 \times T_i^4
\]

Divided by 1-D values

\[
\text{YOC} = \frac{(\sqrt{V t_b \rho_{hs}})^2}{(\sqrt{V t_b \rho_{hs}})_{1-D}} \times (\text{TOC})^4
\]

Prefactor

\[
(\sqrt{V t_b \rho_{hs}}) / (\sqrt{V t_b \rho_{hs}})_{1-D} \sim 50\%
\]

TC8847
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