Direct-Drive Implosions Using Cryogenic D₂ Fuel

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Summary

Direct drive is a robust alternative for ignition on the National Ignition Facility

- The baseline symmetric direct-drive cryogenic D$_2$ campaign has demonstrated target performance consistent with 1-D and 2-D hydrocode predictions.

- Laser and cryogenic target uniformity are approaching the requirements for scaled ignition validation.

- DT cryogenic implosions will be performed before the end of FY05.

- OMEGA EP will be completed by the end of FY07.
OMEGA cryogenic targets are energy scaled from the NIF symmetric direct-drive point design.

Energy $\sim$ radius$^3$; power $\sim$ radius$^2$; time $\sim$ radius.

Gain (1-D) = 45

NIF: 1.5 MJ
- DT ice: 1.69 mm
- DT gas: 1.35 mm

OMEGA: 30 kJ
- D$_2$ ice: 0.46 mm
- D$_2$ gas: 0.36 mm

$\alpha = \frac{P_{\text{fuel}}}{P_{\text{Fermi}}}$

$\alpha \sim 3$ for NIF
$\alpha \sim 4$ for OMEGA
A stability analysis* defines the ignition-scaling performance window for low adiabat implosions

- The NIF gain and OMEGA yield can be related by
  \[ \overline{\sigma}^2 = 0.06 \sigma_{\ell < 10}^2 + \sigma_{\ell \geq 10}^2, \]
  where the \( \sigma_{\ell} \)'s are the rms amplitudes at the end of the acceleration phase*.

The best layer to date is 1.2-μm rms (all modes) with the best regions below 1.0-μm rms

• 24 shadowgraphic views of “x” and “y”
Absorption measurements for cryogenic D₂ shots agree with 1-D hydrodynamic simulations for all pulse shapes.

The average difference between 1-D predictions and absorption measurements is $-1\pm2\%$. 

The diagram shows a graph plotting the relative absorption difference (measured absorption - 1D/1D) (%) against shots (pulse shapes). The graph includes data points for different pulse shapes, denoted as SG1018, $\alpha$402, and $\alpha$402P, with error bars indicating the mean $\pm \sigma_{\text{mean}}$. The graph illustrates how the differences vary for different pulse shapes.
The reaction history and bang time are close to the 1-D predictions for cryogenic D$_2$ implosions

**Shot 35970 ($\alpha \sim 25$)**
- 86-$\mu$m offset, 6.4-$\mu$m ice rms

**Shot 35713 ($\alpha \sim 4$)**
- 15-$\mu$m offset, 4.1-$\mu$m ice rms

$f_{\text{abs}} \begin{cases} \text{Exp.: 0.55$\pm$0.02} \\ \text{1-D: 0.57} \end{cases}$
Preheat estimates for cryogenic targets are well below the threshold of concern (0.1%)

Low-\(\ell\)-mode drive nonuniformities due to OMEGA beams have been significantly reduced

- New DPP’s, better overlap, and beam re-pointing have minimized low-\(\ell\)-mode \((\ell < 6)\) contributions.

\[
\sigma_{\text{tot}}^2 = \sigma_{\text{size}}^2 + \sigma_{\text{pntg}}^2 + \sigma_{\text{balance}}^2
\]

\[
\sigma_{\text{SG3}}^2 = (1.5)^2 + (2.2)^2 + (1.3)^2, \quad \sigma_{\text{tot}} = 3.0\%
\]

\[
\sigma_{\text{SG4}}^2 = (0.6)^2 + (0.7)^2 + (0.6)^2, \quad \sigma_{\text{tot}} = 1.1\%
\]
Hydrodynamic simulations are consistent with implosion data over a wide range of ice roughness and target offset.

Average error of offset $= 10 \text{ \mu m}$
Scaled ignition performance on OMEGA is approaching the predicted equivalence of high gain on the NIF.

Target offset and ice quality presently limit access to low $\bar{\sigma}$ for $\alpha = 4$ campaign.
The near term cryogenic shot plan will be focused on high \( \langle \rho R \rangle_n \) and validating adiabat shaping

- The working physics plan is geared toward direct-drive ignition on the NIF and includes
  1. adiabat shaping validation with pickets
  2. high \( \langle \rho R \rangle_n \)
  3. ignition-scale \( \rho R/DT \) implosions
  4. adiabat shaping validation with Rx drive pulses
  5. advanced cryogenic target designs including
     - fill tubes (NIF CTHS baseline)
     - wetted foams
     - saturn targets (best prospect for PDD on the NIF)
     - cone in shell (FI)

These objectives will be met with \( \sim 1\mu m \) rms ice and TCC offsets of \( \sim 10 \mu m \) (or less).
Tritium will be introduced gradually, following a readiness review in June.

- A second FTS will be complete in July for concurrent $D_2$ cryogenic target production.

- One MCTC will be dedicated to DT operations.
  - At most, one DT implosion per shot day (up to 24/year).

- Potential tritium contamination of the characterization station may limit the throughput for $D_2$ implosions.

- The initial tritium fraction will be 0.1% and be raised incrementally ($\times10$) to reach 50:50 DT by fall 2005.
  - Layering studies can begin with 10% tritium.

- A dedicated cryogenic target test stand is being designed for advanced target development.
  - Maintain production target throughput.
The nonuniformity of the inner ice layer at the end of the accelerating phase will be directly inferred using the OMEGA EP HEPW laser system.

\[ \Delta X_{\text{motion}} = \nu \cdot \Delta t = 5 \times 10^7 \cdot 5 \times 10^{-12} = 2.5 \, \mu m \]

OMEGA EP will be operational in FY07 (two beams) and ready for target physics in FY08

- There are four primary missions.

  1. Extend ICF research capabilities with high-energy and high brightness backlighting
  2. Perform integrated fast-ignition (FI) experiments
  3. Develop advanced backlighter techniques for HED physics
  4. Conduct ultrahigh-intensity laser–matter interaction research
The two short pulse beams can be delivered to both target chambers.

<table>
<thead>
<tr>
<th>Short-pulse performance</th>
<th>Short-pulse Beam 1</th>
<th>Short-pulse Beam 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short pulse (IR)</td>
<td>1 to 100 ps</td>
<td>35 to 100 ps</td>
</tr>
<tr>
<td>IR energy on-target (kJ)</td>
<td>2.6</td>
<td>2.6</td>
</tr>
<tr>
<td>Intensity (W/cm²)</td>
<td>$6 \times 10^{20}$</td>
<td>$\sim 4 \times 10^{18}$</td>
</tr>
<tr>
<td>Focusing (diam)</td>
<td>&gt; 80% in 20 μm</td>
<td>&gt; 80% in 40 μm</td>
</tr>
</tbody>
</table>
The OMEGA EP building was completed in February 2005.

April 2004

January 2005

OMEGA EP Laser Bay

The source laser was installed in April 2005.
An OMEGA EP Use Plan is under development

• The OMEGA EP Use Plan will
  – define the expected operating parameters and availability,
  – the avenues for non-LLE users to obtain access, and
  – initial experimental campaigns.

• The Use Plan will be completed in Spring 2006.
  – An informational and informal discussion meeting
    will be held at the 2005 APS/DPP meeting.
  – A workshop will be held at UR/LLE in December 2005/
    January 2006
    - to allow potential users to propose experiments
      and discuss access availability and
    - to consider capabilities required to carry out the experiments.

• If you wish to be informed of, or participate, in this planning activity
  and be included in the mailing list, contact

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The measured $\langle \rho R \rangle_n$ is close to 1-D for all but the lowest-adiabat implosions.

Ice roughness and target offset appear to limit the measured $\langle \rho R \rangle_n$ for higher-convergence implosions.