Hot-Spot Flow Velocity in Laser-Direct-Drive Inertial Confinement Fusion Implosions

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Summary

3-D nuclear and x-ray diagnostics are used on OMEGA to understand multidimensional effects on laser direct drive implosions

- The 1st and 2nd moments of the primary DT fusion neutron peak are diagnosed with four neutron time-of-flight detectors (3-D nToF).
- 3-D nToF measurements at stagnation indicate a hot-spot flow velocity of 50 to 150 km/s having an inverse relationship with neutron yield.
- Comparison of 3-D hot-spot x-ray imaging* with 3-D nToF measurements reveals the hot-spot elongates along the hot-spot flow velocity direction.

3-D x-ray and nuclear measurements are essential to diagnose the causes of performance limitations in inertial confinement fusion.

K. M. Woo et al., UI2.00002, this conference.
O. Mannion et al., TO5.00002, this conference.
A. Crilly et al., TO5.00001, this conference.
C. Stoeckl et al., PO7.00010, this conference.
Z. Mohammed et al., YO5.00008, this conference.
S. Ivancic et al., UO7.00004, this conference.
Collaborators


Laboratory for Laser Energetics
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Multidimensional effects are seeded by many sources of nonuniformity in laser direct drive.

**Nonuniformity Sources**

- Beam pointing, geometry, timing, laser power
- Target uniformity, Engineering features (e.g., target stalk)
- Ice-shell thickness variation (cryo)

The on-target, laser drive is adjusted by changing initial target position to counteract the measured hot-spot flow velocity.
Asymmetric compression drives a hot-spot flow affecting the 1st and 2nd moments of the primary DT fusion neutrons*

1st moment
(Hot-spot flow velocity)

2nd moment
(Inferred $T_i$)

Six neutron time-of-flight detectors are used on OMEGA to infer hot-spot flow velocity and apparent $T_i$ asymmetry*

The hot-spot center of mass flow velocity is determined from the four measurements.

LOS: line of sight

Neutron yield increases as the hot-spot flow decreases

The direction of hot-spot flow is fairly constant during a shot day, but varies from one shot day to another.
Counteracting the Hot-Spot Flow Velocity

Counteracting hot-spot flow velocity by imposing an $\ell = 1$ drive asymmetry with an initial target offset improves target performance at stagnation.

Three-dimensional measurements provide insight to improve implosion symmetry.
Comparison of 3-D hot-spot imaging with 3-D nuclear measurements of hot-spot flow reveals the hot-spot elongates along flow direction.

**Diagnostic/target orientation**

- **H4**
- **H13**
- **H12**

**Hot-spot flow velocity**

**Target stalk**

**3-D x-ray imaging of hot spot**

- **Spectral range:** $4 \text{ keV} \leq h\nu \leq 8 \text{ keV}
- **Spatial resolution:** 6 to 10 $\mu$m
- **Temporal resolution:** 20 to 40 ps

**Without target offset**

- **Shot 94712**

**Flow direction in field of view**

- **H4 view**
  - *Time-resolved pinhole imager*
  - **126 km/s**

- **H13 view**
  - *Time-resolved Kirkpatrick-Baez (KB) microscope*
  - **39 km/s**

- **H12 view**
  - *Time-integrated KB microscope*
  - **131 km/s**

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Comparison of 3-D hot-spot imaging with 3-D nuclear measurements of hot-spot flow reveals the hot-spot elongates along flow direction.

**3-D x-ray imaging of hot spot**

- Spectral range: $4 \, \text{keV} \leq h\nu \leq 8 \, \text{keV}$
- Spatial resolution: 6 to 10 $\mu\text{m}$
- Temporal resolution: 20 to 40 ps

**Flow direction in field of view**

- H4 view time-resolved pinhole imager
  - 34 km/s
- H13 view time-resolved Kirkpatrick-Baez (KB) microscope
  - 30 km/s
- H12 view time-integrated KB microscope
  - 39 km/s

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Summary/Conclusions

3-D nuclear and x-ray diagnostics are used on OMEGA to understand multidimensional effects on laser direct drive implosions

- The 1\textsuperscript{st} and 2\textsuperscript{nd} moments of the primary DT fusion neutron peak are diagnosed with four neutron time-of-flight detectors (3-D nToF).
- 3-D nToF measurements at stagnation indicate a hot-spot flow velocity of 50 to 150 km/s having an inverse relationship with neutron yield.
- Comparison of 3-D hot-spot x-ray imaging\textsuperscript{*} with 3-D nToF measurements reveals the hot-spot elongates along the hot-spot flow velocity direction.

3-D x-ray and nuclear measurements are essential to diagnose the causes of performance limitations in inertial confinement fusion.

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Z. Mohammed et al., YO5.00008, this conference.
S. Ivancic et al., U07.00004, this conference.
Diagnostics are being developed to measure laser drive on target

Nonuniformity Sources

On-target, laser drive

As a tool to improve the implosion symmetry, the target positioning is adjusted to compensate sources of nonuniformity.

- FCC: frequency-conversion crystal
- F-ASP: stage-F alignment sensor package
- DPR: distributed polarization rotators
- DPP: distributed phase plates
Counteracting hot-spot flow velocity by imposing an $\ell = 1$ drive asymmetry alters the spatial variation in the compressed areal density ($\rho R$).

3-D diagnostics for hot spot and compressed shell are essential.

TIM: ten-inch manipulator
The best-performing implosion on OMEGA achieved an energy-scaled \( \langle \chi_{\text{no } \alpha} \rangle_{\text{scaled}} = 0.74^* \)

<table>
<thead>
<tr>
<th>Metric</th>
<th>Shot 90288</th>
<th>Near-term goal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield</td>
<td>1.6±0.04 × 10^{14}</td>
<td>1.5 × 10^{14}</td>
</tr>
<tr>
<td>( \langle T_i \rangle ) (keV)</td>
<td>4.55±0.3</td>
<td>4.5</td>
</tr>
<tr>
<td>( \langle \rho R \rangle ) (mg/cm^2)</td>
<td>160±12</td>
<td>190 to 200</td>
</tr>
<tr>
<td>( \chi_\Omega = \rho R^{0.61} (0.12Y_{16}/M_{\text{stag}})^{0.34} )</td>
<td>0.174 to 0.18</td>
<td>0.19 to 0.20</td>
</tr>
<tr>
<td>Energy scaled</td>
<td>0.74</td>
<td>0.8 to 0.85</td>
</tr>
<tr>
<td>( \langle P \rangle_{\text{BT}} ) (Gbar)</td>
<td>52.7±7</td>
<td>60 to 70</td>
</tr>
</tbody>
</table>

\(*\) Scaled to \( E_{\text{UV}} = 1.9 \) MJ; V. Gopalaswamy et al., Nature 565, 581 (2019).