Hot-Electron Generation at Direct-Drive Ignition-Relevant Plasma Conditions at the National Ignition Facility

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CH or Si

23° and 30° beams or 45° and 50° beams

Laser intensity ($\times 10^{15}$ W/cm$^2$)

Hot-electron conversion efficiency (%)

0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5

Inner beams, CH

Outer beams, CH

Inner beams, Si

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Summary

A laser-energy conversion efficiency of \( \sim 1\% \) to 3\% into hot electrons with \( T_e \sim 45 \) to 60 keV was inferred

- Planar-target experiments at the National Ignition Facility (NIF) reproduce direct-drive (DD) ignition-relevant plasma conditions
- The properties of hot electrons were inferred using the measured hard x-ray spectra and Monte Carlo simulations
- The beam angle of incidence did not have a strong effect on the hot-electron production
- Hot-electron levels suggest a need for preheat mitigation; the use of Si ablators for preheat mitigation was investigated
Collaborators


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Planar NIF experiments explore laser–plasma interaction (LPI) instabilities and hot-electron production in DD ignition-relevant plasma conditions

Coronal conditions predicted by DRACO radiation–hydrodynamic simulations

<table>
<thead>
<tr>
<th>Parameters at $n_c/4$ surface</th>
<th>OMEGA*</th>
<th>Current NIF DD**</th>
<th>Ignition NIF DD***</th>
<th>Planar NIF</th>
</tr>
</thead>
<tbody>
<tr>
<td>$I_L$ (W/cm$^2$)</td>
<td>$&lt;4 \times 10^{14}$</td>
<td>$4.5 \times 10^{14}$</td>
<td>6 to $8 \times 10^{14}$</td>
<td>5 to $15 \times 10^{14}$</td>
</tr>
<tr>
<td>$L_n$ ($\mu$m)</td>
<td>$&lt;350$</td>
<td>350</td>
<td>600</td>
<td>500 to 700</td>
</tr>
<tr>
<td>$T_e$ (keV)</td>
<td>$&lt;2.5$</td>
<td>3.5</td>
<td>3.5 to 5</td>
<td>3 to 5</td>
</tr>
</tbody>
</table>

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***V. N. Goncharov et al., T05.00003, this conference.
The scaling of hot-electron properties with laser intensity in CH targets was studied using large-angle beams. Absolute-instability thresholds* are exceeded in this experimental design.

\[ \eta_{SRS} = I^{4/3} \left( \frac{n_{e}}{L_{n}} \mu m \right)^{4/3}/2377 \sim 10 \text{ to } 25 \]

\[ \eta_{TPD} = I \left( \frac{n_{e}}{L_{n}} \mu m / (230 T_{e,keV}) \right) \sim 4 \text{ to } 7 \]

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Hot-electron production in CH and Si targets was studied using small-angle beams.

**DRACO-simulated coronal conditions at \( n_c/4 \) (4.5 to 7.5 ns)**

<table>
<thead>
<tr>
<th></th>
<th>N160719-003, CH</th>
<th>N160421-001, CH</th>
<th>N160719-001, Si</th>
</tr>
</thead>
<tbody>
<tr>
<td>( I ) (W/cm(^2))</td>
<td>6 ( \times ) 10(^{14})</td>
<td>11 ( \times ) 10(^{14})</td>
<td>9 ( \times ) 10(^{14})</td>
</tr>
<tr>
<td>( L_n ) (( \mu )m)</td>
<td>670</td>
<td>690</td>
<td>560</td>
</tr>
<tr>
<td>( T_e ) (keV)</td>
<td>3.6</td>
<td>4.4</td>
<td>5.2</td>
</tr>
</tbody>
</table>
Hot-electron properties were inferred using the measured hard x-ray spectra

- Time-integrated hard x-ray spectra obtained using the filter-fluorescer x-ray diagnostic (FFLEX)*

\[ \text{X-ray emission (keV/keV} \cdot \text{sr)} \]

\[ \begin{align*}
0 & \quad 10^9 \\
50 & \quad 10^{10} \\
100 & \quad 10^{11} \\
150 & \quad 10^{12} \\
200 & \quad 10^{13} \\
250 & \quad 10^{13} \\
300 & \quad 10^{13}
\end{align*} \]

\[ h\nu \ (\text{keV}) \]

Outer-beam shots, CH

\[ \begin{align*}
\sim 6 \times 10^{14} \\
\sim 10 \times 10^{14} \\
\sim 15 \times 10^{14}
\end{align*} \ W/cm^2

- Hot-electron energy was inferred from comparing the x-ray spectra and EGSnrc** Monte Carlo simulations

The inferred laser energy to hot-electron conversion efficiency increases from ~1% to 3% with the laser intensity.

- The use of a Si ablator reduces the energy of hot electrons above ~50 keV (relevant to preheat) by ~35%, compared to the relevant CH shots.
- Hot-electron production is attributed to SRS, which dominates LPI in these experiments.*

Hot-electron levels suggest a need for mitigation

• The ignition target performance is negatively affected if more than $\sim 0.15\%$ of the laser energy is coupled into the cold fuel in the form of hot electrons*

• If electron divergence is large, only $\sim 25\%$ of the hot electrons will intersect the cold fuel and result in preheat**

• Electrons with energy below $\sim 50$ keV will be stopped in the ablator and will not preheat the compressed fuel

• Hot-electron preheat mitigation is needed if more than $\sim 0.7\%$ of the laser energy is converted to hot electrons at $T_e \sim 50$ to 60 keV
  – ignition designs with $I > 5 \times 10^{14}$ W/cm$^2$ at $n_c/4$ need preheat mitigation
  – the use of Si ablators for preheat mitigation is investigated

Hot-electron divergence will be investigated in Mo-ball experiments on the NIF.
A laser-energy conversion efficiency of ~1% to 3% into hot electrons with $T_e \sim 45$ to 60 keV was inferred.

- Planar-target experiments at the National Ignition Facility (NIF) reproduce direct-drive (DD) ignition-relevant plasma conditions.
- The properties of hot electrons were inferred using the measured hard x-ray spectra and Monte Carlo simulations.
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