Reducing the Cross-Beam Energy Transfer in Direct-Drive Implosions Through Laser-Irradiation Control

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The loss of hydrodynamic efficiency in direct-drive implosions caused by cross-beam energy transfer can be reduced by changing the irradiation conditions.

**Summary**

- Cross-beam energy transfer (CBET) is due to low-gain SBS sidescattering.
- EM-seeding of SBS sidescattering is due to outer parts of one beam crossing the inner parts of another beam.
- Beam sizes smaller than the target size reduce CBET, but may increase the illumination nonuniformity.

- Experiments with different illumination geometries and detailed spectral analyses have significantly increased our understanding of CBET.
Collaborators


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Cross-beam energy transfer involves EM-seeded, low-gain SBS sidescattering

- EM-seed is provided by outer parts of beams
- Inner parts of beams transfer some of their energy to outgoing parts of other beams
- This process reduces hydrodynamic drive efficiency
- Reducing the beam size can reduce cross-beam energy transfer
Large-shell, room-temperature implosions demonstrate reduced CBET for narrower beams on target

- Large targets: 1400-μm diam
- Phase plates:
  - SG4 focused (860-μm diam at 5% intensity) → narrow focus
  - SG4 defocused (1400-μm diam at 5% intensity) → wide focus
Cross-beam energy transfer significantly affects the time-resolved scattered power

- Near-absence of CBET
  - simulations with and without cross-beam energy transfer are nearly identical
Reducing CBET increases the drive efficiency and causes the x-ray bang time to occur earlier.
The reduced hydrodynamic drive caused by CBET is evident in experimental scattered light spectra.
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Scattered-light spectra of high-intensity implosions lie below CBET prediction and suggest TPD absorption.

Experimental scattered-light spectrum

Wavelength (nm)

351.2
350.8

Relative powers

1.0
0.8
0.6
0.4
0.2
0.0

Time (ns)

0
1
2

$\lambda_L$

$I_{14} = 9.13$

Shot 60000

Shot 60000

$E_{19910}$
Scattered-light spectra of high-intensity implosions lie below CBET prediction and suggest TPD absorption.
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Experimental scattered-light spectrum

- Shot 60000
- Wavelength (nm)
  - $\lambda_L$
  - 351.2

- Relative powers
  - $I_{14} = 9.13$
  - Missing energy = 1.3 kJ out of 26 kJ
  - Exp. scattered light + $f \times$ TPD
  - LILAC + nl + SBS
  - TPD

- Time (ns)
Scattered-light spectra of high-intensity implosions lie below CBET prediction and suggest TPD absorption.

Experimental scattered-light spectrum

Wavelength (nm)

Relative powers

Time (ns)

Equivalent to ~1.3 kJ out of 26 kJ (~5%) possibly pumped into EPW’s
At low intensities ($< 4 \times 10^{14} \text{ W/cm}^2$, overlapped) the LILAC predictions with CBET for scattered light are within 2% of time-integrated measurements.

**Table:**

<table>
<thead>
<tr>
<th>Time (ns)</th>
<th>0.0</th>
<th>0.2</th>
<th>0.4</th>
<th>0.6</th>
<th>0.8</th>
<th>1.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavelength (nm)</td>
<td>351.2</td>
<td>351.0</td>
<td>350.8</td>
<td>350.6</td>
<td>350.4</td>
<td>350.2</td>
</tr>
<tr>
<td>Norm. power</td>
<td>59635 H13</td>
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</table>

**Experimental scattered light**

**Nonlocal + full SBS**

**Nonlocal only**

**Time-integrated absorption (exp.) = 83%**
Simulations with CBET (nonlocal + full SBS) = 84%

**No measureable TPD (3\omega/2)** No HRXD signals
3\omega/2 spectra are indicative of TPD near the Landau cutoff, typical of the nonlinear state of this instability.

Equivalent to \(~1.3\text{ kJ}\) out of \(26\text{ kJ}\) (\(~5\%\)) possibly pumped into EPW's.
3ω/2 spectra are indicative of TPD near the Landau cutoff, typical of the nonlinear state of this instability.

Exp. scattered light + f × TPD

Equivalent to ~1.3 kJ out of 26 kJ (~5%) possibly pumped into EPW’s

HXRD Ch2: 197 pC → 5.6 mJ_{Hx} ~ 30-J energetic electrons
The scattered-light spectra of imploding targets with narrow- and wide-focus illumination agree with CBET predictions.
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Signature of inner parts of beams are nearly absent.

Inner parts of beams are not attenuated by CBET.
CBET using the clamped SBS model cannot spectrally be distinguished from the full SBS model.
The scattered-light spectra are poorly modeled with only nonlocal transport or standard $f = 0.06$ flux limiter.

Signature of inner parts of beams are nearly absent.

Wide focus
1-D *LILAC* simulations with CBET indicate higher absorption but increased drive nonuniformity for beams smaller than the target.
Summary/Conclusions

The loss of hydrodynamic efficiency in direct-drive implosions caused by cross-beam energy transfer can be reduced by changing the irradiation conditions.

- Cross-beam energy transfer (CBET) is due to low-gain SBS sidescattering.
- EM-seeding of SBS sidescattering is due to outer parts of one beam crossing the inner parts of another beam.
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- Experiments with different illumination geometries and detailed spectral analyses have significantly increased our understanding of CBET.
\( \omega/2 \) spectra probe different phase space of TPD with slightly different time-evolution from \( 3\omega/2 \) spectra

![Graph](image)

- **Relative powers**
  - 0.0 to 1.0

- **Time (ns)**
  - 0 to 2

- **Wavelength (nm)**
  - 680 to 720

**Labels**
- \( \omega/2 \) spectrum
- Shot 60000
- SRS 30
- TPD
- LILAC + nl + SBS
- Equivalent to \(~1.3\) kJ out of \(~26\) kJ (\(~5\%) possibly pumped into EPW’s

**Legend**
- \( I_{14} = 9.13 \)
- Exp. scattered light + \( f \times TPD \)

**Additional Information**
- HXRD Ch2: 197 pC \( \rightarrow \) 5.6 mJx \( \rightarrow \) 30- to 60-J preheat
Time-integrated images of the imploding target are edge-enhanced and may also reflect cross-beam energy transfer.

CTCD camera can be converted to $\omega/2$ imaging with a mere change of filter, yielding information on $\omega/2$ generation processes.