A Neutron Temporal Diagnostic for High-Performance DT Cryo Implosions on OMEGA
Summary

A new neutron temporal diagnostic (NTD) has been built for high-yield DT cryo implosions on OMEGA

- The neutron background and the large scintillator standoff (20 cm) required to clear the cryo shroud severely limits the quality of the data on the previous NTD system on high-performance DT cryo implosions
- The cyroNTD diagnostic was installed in port P11 close to the equator of the target chamber, allowing the scintillator to be inserted to 9 cm
- The ROSS streak camera for the cyroNTD is located in the OMEGA EP plenum for >100× improvement in the neutron shielding
- A ~16-m-long relay system was designed to transport the light from the scintillator to the photocathode with <20-ps group velocity dispersion
- With the standard 3-ns sweep window, the system has a measured impulse response of 40±10 ps, which allows a 70-ps neutron pulse to be measured with 10% accuracy
- Preliminary measurements with the 1.5-ns sweep window show an impulse response of 25±10 ps, which allows a 50-ps neutron pulse to be measured with 10% accuracy
The NTD measures the neutron production rate and bang time.
The neutron production rate is inferred from the unfolded scintillator signal.
The P11-NTD delivers the instrument performance required to support the current and future LLE cryogenic campaign.

<table>
<thead>
<tr>
<th>Performance metric</th>
<th>Performance status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum burnwidth</td>
<td>50 ps</td>
</tr>
<tr>
<td>Bang-time measurement accuracy</td>
<td>±50 ps</td>
</tr>
<tr>
<td>Detectable DD neutron-yield range</td>
<td>$5 \times 10^9$ to $1 \times 10^{13}$</td>
</tr>
<tr>
<td>Detectable DT neutron-yield range</td>
<td>$5 \times 10^{10}$ to $1 \times 10^{15}$</td>
</tr>
</tbody>
</table>
Cryo-NTD beam transport uses seven mirrors and four relay stages to cover 16.2 m from the scintillator to the ROSS.

Scintillator/nose cone

Vacuum window

RL*1

Plenum and shield wall

RL2

RL3

RL4

ROSS

(90° periscope fold not shown)

*RL: relay lens
Group velocity dispersion is less than 20 ps over a 340- to 500-nm bandwidth
The ROSS streak camera of the H5 NTD is placed close to the target chamber in a 10-cm-thick CH shield.
Neutron noise was minimized by placing the streak camera ~11 m from the target with ~170 cm of shielding.
The P11-NTD maintains excellent CCD image signal-to-noise ratios throughout the typical OMEGA DT neutron yield range.

Neutral density filters are required to limit peak streak tube current at yields $>2 \times 10^{13}$.

Neutron background noise continues to rise linearly.

Low signal yields a shot noise limited measurement.

Peak CCD image signal-to-noise (SNR) response:

- **10-cm insertion depth**
- **Typical OMEGA DT yield range**
- **Neutron background noise continues to rise linearly**

$\text{DT neutron yield}$

$\text{SNR}$

$10^{11}$ $10^{12}$ $10^{13}$ $10^{14}$ $10^{15}$

$10^{0}$ $10^{1}$ $10^{2}$
The P11-NTD provides superior data quality on high-yield implosions compared to previous NTD diagnostics.

<table>
<thead>
<tr>
<th>LLNL H5-NTD</th>
<th>LLE H5-NTD</th>
<th>LLE P11-NTD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cryo shot 69515</td>
<td>Cryo shot 76358</td>
<td>Cryo shot 76358</td>
</tr>
<tr>
<td>DT yield: 2.95 × 10^{13}</td>
<td>DT yield: 2.61 × 10^{13}</td>
<td>DT yield: 2.61 × 10^{13}</td>
</tr>
</tbody>
</table>
The P11-NTD leverages the power of the ROSS streak-camera platform to provide a well-characterized camera response.

---

**Sweep-time base calibration**

- **Streak-tube geometric distortion**
  - Grid point array

- **Ramp-driver sweep-speed profile**
  - On-shot 2-GHz comb
  - Dwell time plot

**Camera bandwidth characterization**

- **Static line spread function**
  - ADUs ($\times 10^6$)

- **Sweep speed (ns)**
  - 13
  - 6
  - 3 (nominal)
  - 1.5

- **Temporal resolution (ps)**
  - 60
  - 25
  - 15
  - 7

---

Time base corrected with 1% accuracy

15-ps on-shot camera resolution
The impulse response of P11-NTD was measured using short laser pulses (10 ps) from OMEGA EP on an Au foil.

- The high-intensity (>10^{17} \text{ W/cm}^2) laser pulse generates hard x rays with energies >200 keV.
- These x rays penetrate through the heviment shielded nose cone and generate light similar to the high-energy neutrons.
- The temporal width of the x-ray pulse is of the order of the width of the laser pulse.
With the standard 3-ns sweep window, P11-NTD has a measured impulse response of $40 \pm 10$ ps

- Using an intrinsic width of the x-ray signal, $25 \pm 10$ ps, the measured width of $\sim 50$ ps deconvolves to an impulse response of $40 \pm 10$ ps

- The absolute timing of P11-NTD is calibrated against NTD with an accuracy of $\sim 50$ ps

*FWHM: full width at half maximum
Preliminary measurements with a 1.5-ns sweep window show a shorter impulse response of $25\pm10$ ps.

- Using an intrinsic width of the x-ray signal, $25\pm10$ ps, the measured width of $35\pm5$ ps deconvolves to an impulse response of $25\pm10$ ps.
The new neutron temporal diagnostic provides an accurate measurement of the neutron production rate.

- The NTD measurements show an earlier peak and burn truncation for the current cryo implosions.
It is conceptually quite simple to transfer the P11-NTD design for implementation on the NIF

- The $\sim 10^4 \times$ larger yields on the NIF will require significantly more shielding
  - An additional 1 m of concrete or equivalent compared to P11-NTD is probably necessary

- An $\sim 20$-m-long optical relay system could transport the light outside the 2-m-thick bio-shield

- With a typical neutron production width of $\sim 150$ ps for sub-ignition experiments on the NIF, the time-resolution requirements would be relaxed compared to OMEGA

- The impulse response of a NIF-NTD could be calibrated in-situ using the NIF/ARC short-pulse capability

- A project has been established in Prof. Petrasso’s group at MIT to evaluate designs for a NTD on the NIF (Brandon Lahmann, Ph.D. student)

- A NTD-like setup is being installed on LLE’s short-pulse Multi-Terawatt (MTW) Laser System, which can be used to qualify new scintillator materials and calibration strategies
The OMEGA Target Bay section includes the scintillator-transport mechanism, zoom-optics assembly, and image-relay hardware.
The scintillator is placed inside a telescoping mechanism re-entrant into the target chamber.
The final image relay section includes focusing optics, a remote-controlled filter wheel, and the ROSS streak camera.