Primer to ARC –
Capability bounds, targets, and platforms

NIF & JLF User Group Meeting

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David Martinez
(on behalf of the ARC team)
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ARC enables a variety of applications on NIF

Compton Radiography of ICF experiments

X-ray Radiography of complex hydrodynamics

Directed beams of MeV protons, positrons, deuterons, & neutrons

Proton radiography

Pair plasma creation

Laser-wakefield driven keV and MeV sources for applications


F. Albert, N. Lemos
ARC is a high energy short pulse laser that is integrated into NIF

1. ARC high contrast front end generates stretched (chirped) pulse
2. NIF beamlines are used to amplify the stretched pulse
3. Amplified pulses extracted and recompressed for focusing on target
Compressor vessel
Parabolic Mirrors
ARC Diagnostic Table (ADT)
B354 f# = 22 (diagonal)
B353 f# = 25 (diagonal)
PORT 77.5°, 204.38°

NIF switchyard and target area highlighting ARC beams
ARC current performance specifications are based on measurement, modeling and design

<table>
<thead>
<tr>
<th>ARC Beamlet</th>
<th>Current or Near Term Capabilities</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Number</strong></td>
<td>4</td>
</tr>
<tr>
<td><strong>Energy &amp; pulse duration</strong></td>
<td>250 J @ 1* ps</td>
</tr>
<tr>
<td><strong>Focal spot (~ 30 ps, ~ 1 kJ)</strong></td>
<td>10-30% of energy at ≥1e17 W/cm² ≥30-50% in 150 µm spot</td>
</tr>
<tr>
<td><strong>Alignment accuracy rms (X&lt;sub&gt;ARC&lt;/sub&gt;, Y&lt;sub&gt;ARC&lt;/sub&gt;)</strong></td>
<td>(45, 34) µm</td>
</tr>
<tr>
<td><strong>Pointing range from TCC (ARC)</strong></td>
<td>(±50,±50,+10/-45)mm ARC perspective, left/right, Up/down, Focus</td>
</tr>
<tr>
<td><strong>Target position range (NIF)</strong></td>
<td>(+45, +45, +30 )**</td>
</tr>
<tr>
<td><strong>Beamlet-to-beamlet pointing</strong></td>
<td>1.26 mm perpendicular, 2mm along focus. (Within same beamline)</td>
</tr>
<tr>
<td><em><em>Pre-pulse contrast for 1</em> ps pulse</em>*</td>
<td>80 dB (t &lt; -1.5 ns), 70 dB (t &lt; -200 ps)</td>
</tr>
<tr>
<td><strong>Timing Accuracy ARC to ARC</strong></td>
<td>10 ps rms (any beamlet wrt any other beamlet)</td>
</tr>
<tr>
<td><strong>Timing Accuracy ARC to NIF</strong></td>
<td>30 ps rms (any beamlet wrt NIF)</td>
</tr>
<tr>
<td><strong>Delay relative to NIF</strong></td>
<td>Up to 70 ns (any beamlet wrt NIF)</td>
</tr>
<tr>
<td><strong>Delay of B beamlet wrt A beamlet</strong></td>
<td>Up to 30 ns (B after A)</td>
</tr>
<tr>
<td><strong>Delay of B354 wrt B353</strong></td>
<td>Up to 3.6 ns, [8 ns planned] (B353 after B354)</td>
</tr>
</tbody>
</table>

*Aberrations in NIF chain produce a ~2ps pulse duration on target (calculated).

**limits based on Target alignment system (TAS) center position, actual target may have additional restrictions and clearance requirements
The high contrast ARC front end enables temporally clean pulses on target

Pre-pulse contrast for 1* ps pulse 80 dB (t < -1.5 ns), 70 dB (t < -200 ps)
ARC is commissioned to operate at four defined pulse widths: 1*, 10, 30 and 38 ps

*Aberrations in NIF chain produce a ~2ps pulse duration on target (calculated)
The on-shot ARC focal spot is calculated with a benchmarked propagation model.

<table>
<thead>
<tr>
<th>Enclosed energy</th>
<th>Diameter (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>95%</td>
<td>1950</td>
</tr>
<tr>
<td>80%</td>
<td>394</td>
</tr>
<tr>
<td>50%</td>
<td>130</td>
</tr>
</tbody>
</table>

Focal spot (~ 30 ps, ~ 1 kJ)

10-30% of energy at ≥1e17 W/cm² ≥30-50% in 150 µm spot

ARC beamlet fluence Strehl ratio varies from 0.2-0.4
Facility performance shots periodically test pointing, beamlet timing and x-ray conversion efficiency with a gold foil.

**Upper SXI View of performance target**

- ARC beams on Au foil
- Au coated Si washer holding 50μm Au plate
- Holes etched into Si washer

### TCC Pointing

- Pointing Difference ARC perspective
- Delay Difference from Expected (ps)
  - A to B: 1.1 ps
  - B353 to B354: 7.8 ps
  - B354B Residual*: 6.4 ps

### ARC beamlet timing

- Delay from N200921-001 (RI: J. Williams)
  - A to B: 1.1 ps
  - B353 to B354: 7.8 ps
  - B354B Residual*: 6.4 ps

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Results from N200921-001 (RI: J. Williams)
New platforms and capabilities are managed through the Advanced radiographic capability integrated product team (ARC IPT)

- Responsible for integrating and coordinating the use of ARC, including the commissioning of new capabilities, new platforms and ARC performance.

- Includes representatives from users, review groups, ARC laser team and facility operations teams.

- Establishes the priority for development activities and group provides guidance, training and documentation for ARC users.

- The ARC IPT is responsible for the platform development and ARC performance shots — Test beam pointing, X-ray conversion efficiency and ARC beamlet to beamlet timing.
For ARC Radiography platforms we use point projection radiography

\[ M = \frac{(v + u)}{u} \]

Resolution depends on the projected size toward the diagnostic

Technique is susceptible to background due a required large aperture to avoid clipping the projections

The High Energy backlighter platform provides a test bed for new techniques on the NIF

Example of a HEBL platform

- Simplified Backlighter target to test requirements
- Test objects are used to quantify metrics.
  - Source size
  - Spectrum
  - Signal / Noise
  - Contrast

All current ARC backlighters on the NIF use a broadband x-ray emission (Bremsstrahlung) for backlighting.
Several experiments utilize the plastic parabolic plasma mirror backlighters to increase the ARC x-ray signal over a bare wire.

Enhanced energy coupling due to plasma-mirror surface generated by ARC pre-pulse.

Conversion Efficiency increases 3x-4x using target mounted plasma mirrors.

A reproducible sufficiently bright x-ray source for Compton Radiography is developed.

Tommasini et al. APS DPP Y13 (2019), Tommasini et al. (To be submitted)
For experiments using the NIF 3w lasers, the 1w residual light needs to be considered for performance and machine safety.

The wedge focus lens essentially deflects the $1\omega$ and $2\omega$ light from $3\omega$ best focus.

With all NIF beams pointed to a hohlraum the deflected 1w light creates a halo around TCC.
Unconverted light shields are used to protect the backlighter from $1\omega$ light

The unconverted light shield protects the ARC beams and backlighter from:

- Preheat

- Plasma from blocking the ARC propagation path

- Preventing NIF 1w light from reflecting into ARC or visa versa

- Curved, Dimpled and rippled surfaces are used to manage $1\omega$ reflections

Pushered single shell ARC Target
Platform: 2DConARC PSS
Variations of the HEBL target have been used to develop several ARC radiography platforms.

<table>
<thead>
<tr>
<th>Platform</th>
<th>Compton Radiography</th>
<th>Complex Hydro</th>
<th>PSS ARC</th>
</tr>
</thead>
<tbody>
<tr>
<td>BL</td>
<td>Au, 25-10um diam with U-flags</td>
<td>W, 13µm wire diam</td>
<td>Au 25µm wire diam with U-flags</td>
</tr>
<tr>
<td>BL axis</td>
<td>DIM 90-78</td>
<td>DIM 90-78</td>
<td>TANDM 90-124</td>
</tr>
<tr>
<td>BL Standoff</td>
<td>7-9 mm</td>
<td>28-45 mm</td>
<td>30 mm</td>
</tr>
<tr>
<td>Field of view</td>
<td>300 µm</td>
<td>1.8 or 5mm</td>
<td>600 µm</td>
</tr>
<tr>
<td>Temp</td>
<td>Cryo</td>
<td>Warm</td>
<td>Warm</td>
</tr>
<tr>
<td>Diagnostic</td>
<td>AXIS &amp; Image plate</td>
<td>Image plate</td>
<td>AXIS &amp; Image plate</td>
</tr>
<tr>
<td>Number of backlighters</td>
<td>Two, with ≤ 0.2 ns delay</td>
<td>One</td>
<td>Two; 0.4ns delay</td>
</tr>
</tbody>
</table>
Pair plasma Discovery Science experiments utilized CPC cones to produce positrons with $10^{18}$ W/cm$^2$ Laser intensities.

First campaign to demonstrate CPC cone targets enhance the hot electron temperature

Compound parabolic concentrator (CPC)* enables pair production on NIF.

*A. G. MacPhee et al., Optica, 7 (2), 129 (2020)
Pair plasma platform RIs (H. Chen, J. Williams)
Several groups are now utilizing CPC cones for MeV proton production

Multiple MeV sources generated on a single experiment to test pulse shaping

Using multiple ARC beamlets the proton energy was improved by tailoring the pulse shape by laser arrival time

PI: D. Mariscal
MeV Source group is using multiple CPC cones to generate bright x-ray sources

Building dose over ns

Pulse #1
1.2 kJ

Pulse #2
1.2 kJ

3ns

2 x CPC cones

MeV photon spectrum from diagnostic suite

ARC is being used to generate multiple pulses of MeV photons to increase overall dose.

Kerr at al., submitted to PoP
Wakefield acceleration has been demonstrated to produce an electron beam >100 MeV

ARC $T_0 + 5$ ns
1 ps, 250 J

He Gas tube $10^{19}$ cm$^{-3}$

NIF $T_0$
(4 x (88 ps, 56 J)

NIF $T_0$
2 x (88 ps, 56 J)

New W-NEPPS diagnostic

$e^-$ beam profile

$[\text{mrad}]$

1.2 µC charge

$e^-$ spectrum

2-temperature spectrum
$T_1 = 1.5$ MeV
$T_2 = 20.5$ MeV

PI: F. Albert
Summary

- ARC produces 4 quasi-independent petawatt-class lasers from B353 and B354
  - Commissioned at 4 pulse widths: 1, 10, 30, and 38 ps
  - Peak intensity is limited by large F# (22-25, rectangular and based on diagonal)
  - ARC laser performance is monitored through the ARC diagnostic table and modeled with VBL

- Experiments using ARC have supported multiple missions through X-ray backlighting

- Innovative use of CPC cones has been demonstrated through Discovery Science program