The MegaJoule Direct Drive Campaign: NIF Experiments on the Pathway to MJ Yield

Energy coupling/symmetry

Hot electron preheat

Laser imprint

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Laboratory for Laser Energetics
Summary

Current MJ-scale experiments lay the groundwork for high-yield direct-drive implosions on the NIF in the 2020’s

- Extrapolation of direct-drive implosion performance from OMEGA to ignition scale on dedicated physics experiments at NIF scale

- The MegaJoule Direct Drive (MJDD) campaign on NIF includes three primary physics objectives:
  1) **Hot electron preheat** has been measured at close to tolerable levels, partially using mid-Z layers, and shown to originate from stimulated Raman scattering
  2) **Implosion symmetry and energy coupling** (including cross-beam energy transfer) has been controlled with wavelength detuning, contoured shells, and beam pointing
  3) **Laser imprint** experiments have produced x-ray radiography data to benchmark levels of imprint-related instabilities and partial mitigation with multi-FM SSD or high

- Current NIF capabilities limit high-performance polar-direct drive (PDD) implosions and convergence exploding pushers

A staged set of proposed facility improvements will allow for increased convergence...
Collaborators

University of Rochester
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Lawrence Livermore National Laboratory

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Naval Research Laboratory

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General Atomics

J. F. Myatt
University of Alberta

L. Antonelli
University of York

R. Scott and K. Glize
Rutherford Appleton Laboratory

A. Colaitis
CELIA
Outline

- Laser direct-drive inertial confinement fusion
  - Scaling and motivation for NIF experiments
- MJDD experiments on NIF
  - LPI/hot electron preheat
  - Laser energy coupling/CBET/PDD symmetry
  - Laser imprint
- Current high-yield PDD implosions and pathway to MJ yield
Laser direct drive is one of three main approaches to achieving inertial confinement fusion ignition and high yield.

**Laser indirect drive**
- LLNL lead laboratory (LANL) Facility
  - NIF
  - OMEGA

**Laser direct drive**
- LLE lead laboratory (NRL, LLNL, LANL) Facility
  - OMEGA
    - NIF
    - NIKE

**Pulsed-power magnetized fusion**
- SNL lead laboratory (LLNL, LANL, LLE) Facility
  - Z
    - Omega
    - NIF
Most direct-drive experiments to produce high-performance (albeit ~1/4 of ignitor scale) implosions are done on OMEGA, which is designed for LDD experiments.

**OMEGA Advantages for LDD**
- Symmetric illumination
- Circular beam spots (ideal for symmetric illumination)
- State-of-the-art beam smoothing (2D smoothing by spectral dispersion, polarization smoothing)
- Cryogenic capability for LDD
Motivation

NIF has laser energy (1.9 MJ) closer to ignition scale, but is not (yet) optimized for high-performance direct-drive implosions.

Omega Advantages for LDD
- Symmetric illumination
- Circular beam spots (ideal for symmetric illumination)
- State-of-the-art beam smoothing (2D smoothing by spectral dispersion, polarization smoothing)
- Cryogenic capability for LDD

NIF optimized for indirect-drive
- Polar illumination
- Beams must be defocused for LDD
- Limited beam smoothing
- No LDD cryo capability

Despite limitations, NIF can be utilized to learn about direct drive physics at ignition-relevant scales now, and with some improvements to the facility, work towards high-performance implosions.
Motivation

Current OMEGA cryogenic implosion yield extrapolates to ~570 kJ at 2 MJ laser drive assuming hydrodynamic scaling is valid.
Motivation

In this context, there are two major thrusts of the direct-drive ICF effort, encompassing experiments on both OMEGA and NIF.

1) Improve performance on OMEGA*

In this context, there are two major thrusts of the direct-drive ICF effort, encompassing experiments on both OMEGA and NIF.

1) Improve performance on OMEGA*

2) Focused on assess/validate MJDD campaign experiments, necessarily operating on scaling: Energetic preheat, improved performance, cryo implosions at NIF.

Motivation

NIF experiments achieve ignition-relevant coronal plasma conditions that are inaccessible in OMEGA implosions

2D DRACO simulated plasma conditions at

<table>
<thead>
<tr>
<th></th>
<th>NIF ignition scale</th>
<th>NIF planar experiments</th>
<th>NIF sub-scale implosions</th>
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</thead>
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<tr>
<td>$L_n$ (µm)</td>
<td>600</td>
<td>400-700</td>
<td>400</td>
</tr>
<tr>
<td>$T_e$ (keV)</td>
<td>3.5 to 5</td>
<td>3 to 5</td>
<td>3.2</td>
</tr>
</tbody>
</table>

$n_c/4$ density represents region where LPI occurs

~0.1-0.25$n_c$
Outline

- Laser direct-drive inertial confinement fusion
  - Scaling and motivation for NIF experiments
- MJDD experiments on NIF
  - LPI/hot electron preheat
  - Laser energy coupling/CBET/PDD symmetry
  - Laser imprint
- Current high-yield PDD implosions and pathway to MJ yield
LPI and hot electron preheat has been studied in both planar and spherical geometries to determine preheat levels and assess mitigation at ignition-relevant scale lengths.

**Preheat in cryo implosions**

Direct-drive implosion

DT fuel

$\frac{n_c}{4}$ surface

CH ablator

**NIF experimental platforms**

Planar platform
(to study LPI mechanisms and hot electron production)

Spherical
(to study coupling to reactor)

CH or Si

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

**n_c/4 conditions**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>NIF Ignition scale</th>
<th>NIF Planar experiments</th>
<th>NIF Spherical experiments</th>
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<tbody>
<tr>
<td>$L_n$ (µm)</td>
<td>600</td>
<td>400-700</td>
<td>400-700</td>
</tr>
<tr>
<td>$T_e$ (keV)</td>
<td>3.5 to 5</td>
<td>3 to 5</td>
<td>3.2</td>
</tr>
<tr>
<td>$I_L$ (W/cm²)</td>
<td>$(6-10)\times10^{14}$</td>
<td>$(6-15)\times10^{14}$</td>
<td>3-6×10^{14}</td>
</tr>
</tbody>
</table>

Designer: A. Solodov
Planar LPI experiments established the predominance of stimulated Raman scattering (SRS) as a hot electron source.

NIF: $L_n = 525 \mu m$
$T_e = 4.5$ keV

OMEGA: $L_n = 150 \mu m$
$T_e = 2.8$ keV

M. J. Rosenberg et al., *Phys. Plasmas* 27, 042705 (2020)
Planar LPI experiments established the predominance of stimulated Raman scattering (SRS) as a hot electron source, the intensity scaling of preheat, and Si mitigation.

- **NIF:** $L_n = 525 \ \mu m$, $T_e = 4.5 \ \text{keV}$
- **OMEGA:** $L_n = 150 \ \mu m$, $T_e = 2.8 \ \text{keV}$

**OMEGA spherical experiment (TPD)**

**Preheat in implosions depends not only on hot electron production, but divergence/coupling to the inner portion of the shell**

M. J. Rosenberg et al., *Phys. Plasmas* 27, 042705 (2020)

A. A. Solodov et al., *Phys. Plasmas*
A PDD implosion platform, using Ge-doped layers, was adapted from OMEGA* to diagnose preheat in the inner portion of the shell.

**NIF target designs**

[Diagrams showing target designs with dimensions and materials indicated]

Design: A. Solodov

For an identical laser drive and identical hot electron source, the difference in hard x-rays $\propto$ hot electron energy deposited in Ge-doped layer

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*Platform based on A. Christopherson, et al. (subm...
Hard x-ray (HXR) emission on NIF shows the expected variation with Ge-layer thickness, with identical LPI

**Average time-resolved SRS signal**

- **59-μm dopant**
- **No dopant**
- **47-μm dopant**

**Time-integrated HXR signal**

- **59-μm dopant**
- **No dopant**
- **47-μm dopant**

Identical LPI/hot e⁻ source  
Different HXR emissions
Hot electron preheat in NIF implosions is inferred to be \(~0.2\%\) of incident laser energy over the inner \(~80\%\) of unablated shell, and \(~2\times\) lower with Si layer.

Analysis: A. Solodov

This level of preheat is close to \(~0.15\%\) limit for direct-drive ignition design.
Hydrodynamically-scaled version of this experiment on OMEGA shows that a similar fraction of laser energy coupled to the inner shell as preheat.

These results support validity of hydro-scaling in warm implosions, though hot electron attenuation at the outer ablator is important and will have to be accounted for in cryogenic implosions with a large laser.
The goal of NIF experiments is to determine the parameter regime (e.g. intensity) that produces acceptably low preheat.

![Graph showing hot-electron energy deposited in the unablated shell against incident laser intensity. The graph includes data points for CH ablator and CH ablator with a Si layer.]

**Analysis:** A. Solodov
The goal of NIF experiments is to determine the parameter regime (e.g. intensity) that produces acceptably low preheat.

Goal of NIF experiments this year is to calculate preheat vs. intensity with and without a Si layer.
These data can be used to estimate likely preheat levels in ignition-scale cryogenic at $10^{15}$ W/cm$^2$ on-target intensity

<table>
<thead>
<tr>
<th>Description</th>
<th>Multiplier</th>
<th>Preheat (% of laser)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preheat into inner 80% of unablated shell in warm subscale NIF implosion</td>
<td>-</td>
<td>~0.2%</td>
</tr>
<tr>
<td>Increase scale length to full scale*</td>
<td>~1.5-2</td>
<td>~0.3-0.4%</td>
</tr>
<tr>
<td>Increase convergence ratio at end of pulse</td>
<td>~0.4-0.8</td>
<td>~0.15-0.3%</td>
</tr>
<tr>
<td>DT shell and some DT in ablator</td>
<td>~1-1.8</td>
<td>~0.15-0.5%</td>
</tr>
<tr>
<td>Improve beam smoothing</td>
<td>~0.8</td>
<td>~0.12-0.4%</td>
</tr>
<tr>
<td>Si layer</td>
<td>~0.5</td>
<td>~0.06-0.2%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td>~0.1-0.2%?</td>
</tr>
</tbody>
</table>

On-target intensity close to $10^{15}$ W/cm$^2$ looks to be OK (so far) for preheat – further experiments are planned to study effect of convergence, mitigation with Si dopant, and ignition-scale capsules

Note: current preheat results are near-“worst case scenario” given poor beam smoothing
Energy coupling/symmetry experiments have been conducted in spherical-geometry platforms at a variety of convergence ratios.

**PDD implosion platform (CBET/Δλ)**

- CH
- 20 atm D$_2$
- 1100-1200 μm
- 80-120 μm
- 1060 μm
- CR ~12

**“Exploding pusher” platform**

- CH
- 22-30 μm
- D2
- 1.5-2.5 mm
- CR ~7

**Solid sphere radiography platform**

- CR =1

**Integrated implosion experiment**

**Focused coupling experiment**
In polar direct drive (PDD) implosions, cross-beam energy transfer (CBET) is a primary energy loss mechanism and occurs predominantly near the equator. CBET is the transfer of laser energy from ingoing (pump) rays to outgoing (probe) rays. Wavelength detuning ($\Delta\lambda$) between interacting beams is one option for CBET mitigation.

P. B. Radha et al., *Phys. Plasmas*
PDD implosions used cone-swapping to produce hemispheric wavelength detuning across the equator

Cone-swapping for $\Delta \lambda$ across the equator

(a) Port-color arrangement
Outer cones, $\lambda_3$
$\theta = 45^\circ, 50^\circ$

Inner cones, $\{\lambda_1, \lambda_2\}$
$\theta = 23^\circ, 30^\circ$

(b) Port-color repointing; southern cone swapping

Hemispheric $\Delta \lambda_0$

$\Delta \lambda_0 = \{\lambda_1, \lambda_2, \lambda_3\}$

Indicates quad-split ports

Design and simulations: J. Marozas
X-ray analysis: M. Hohenberger and D. Turnbull
Energy coupling/symmetry

PDD implosions with hemispheric ±2.3 Å (UV) demonstrated partial mitigation of CBET, as predicted by 2D DRACO simulations.

Cone-swapping for $\Delta \lambda$ across the equator

(a) Port-color arrangement

Outer cones, $\lambda_3$
$\theta = 45^\circ, 50^\circ$

Inner cones, $\{\lambda_1, \lambda_2\}$
$\theta = 23^\circ, 30^\circ$

(b) Port-color repointing; southern cone swapping

$\Delta \lambda_0 = \{\lambda_1, \lambda_2, \lambda_3\}$

Indicates quad-split ports

X-ray radiographs

Simulation

Experiment

N160405
$\Delta \lambda_0 = \{0, 0, 0\}$

N160821
$\Delta \lambda_0 = \{2.3, 2.3, -2.3\}$

N170102
$\Delta \lambda_0 = \{2.3, 2.3, -2.3\}$

Design and simulations: J. Marozas
X-ray analysis: M. Hohenberger and D. Turnbull

- ±2.3 Å (UV) is current NIF limit – need >±3 Å, ideally ±6 Å for greatly enhanced energy gain.
- Flexible color/port-mapping will be implemented in 2022 to avoid cone-swapping and other issues.

One problem for implosions is that we have been unable to simultaneously control the ablation front and inner shell trajectories – shell puffing up due to imprint.

**Backlit image:** $V_{\text{imp}}$ matches within 1%

**Self-emission image:** $V_{\text{imp}}$ overpredicted by 9%, attributed to imprint and Rayleigh-Taylor

Concern about imprint has led our energy coupling campaign to lower convergence.

P. B. Radha et al., Phys. Plasma
Energy coupling/symmetry

One problem for implosions is that we have been unable to simultaneously control the ablation front and inner shell trajectories – shell puffing up due to imprint.

![NIF PDD implosion diagram](image1)

**NIF PDD implosion**
(0.65 MJ, 1.2 x 10^{15} W/cm^2)

![2D DRACO simulated density diagram](image2)

**2D DRACO simulated density**
(with laser imprint)

![Shell trajectory](image3)

**Shell trajectory**

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**Backlit image:** $V_{imp}$ matches within 1%

**Self-emission image:** $V_{imp}$ overpredicted by 9%, attributed to imprint and Rayleigh-Taylor instability.

Concern about imprint has led our energy coupling campaign to lower convergence.

P. B. Radha et al., *Phys. Plasma*
Lower convergence implosions, less sensitive to imprint, are now being assessed/improved to improve energy coupling and symmetry.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>“Standard” implosions</th>
<th>“Exploding pusher”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shell diameter</td>
<td>2.3 mm</td>
<td>3-5 mm</td>
</tr>
<tr>
<td>Shell thickness</td>
<td>120 μm</td>
<td>25 μm</td>
</tr>
<tr>
<td>Primary implosion mechanism</td>
<td>Ablation/compression</td>
<td>Shock</td>
</tr>
<tr>
<td>Convergence ratio</td>
<td>~12</td>
<td>~7</td>
</tr>
<tr>
<td>Physics issues</td>
<td>Laser energy coupling</td>
<td>Laser energy coupling</td>
</tr>
<tr>
<td></td>
<td>Hydro instabilities (e.g.</td>
<td>(less susceptible to</td>
</tr>
<tr>
<td></td>
<td>imprint-seeded RT)</td>
<td>instabilities)</td>
</tr>
</tbody>
</table>
Exploding pusher experiments studied shell contouring as a means to improve implosion symmetry and improve energy coupling along the equator.

- 800 kJ, 280 TW laser drive
- Shell contoured designed based on 2D DRACO simulations of previous experiment

Target fabrication: General Atomics

- AFM Trace 1 vs. 4.5um Amplitude Ideal P2
- Shell thicker near the poles, thinner near the equator

Design: P. Mock
The contoured shell eliminated a 5% in-flight P2, in agreement with post simulations.
Energy coupling/symmetry

The effect of the shell contour on performance was likely positive*, though complicated by differences in gas pressure

<table>
<thead>
<tr>
<th>Parameter</th>
<th>N200715-001</th>
<th>N201021-002</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shell contour</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Laser energy</td>
<td>785 kJ</td>
<td>804 kJ</td>
</tr>
<tr>
<td>Gas pressure</td>
<td>6.57 atm</td>
<td>5.46 atm</td>
</tr>
<tr>
<td>DD-n yield</td>
<td>1.1e12</td>
<td>1.1e12</td>
</tr>
</tbody>
</table>

*Yield was the same, but this is likely attributed to differences in gas pressure on the shot with the contour, which suggests caused a ~30-40% drop in yield.
Recent experiments demonstrated control of symmetry and energy coupling through laser pointing and pulse shaping.

Exploding pusher
~700 kJ
~280 TW

SAGE (old) pointing

D2 gas

~24 μm

Design: J. Marozas

N201220-002

Per-Beam Laser Power

0 0.5 1 1.5
Time (ns) 0 1 2 3 4

DRACO pre-shot
3.4 ns

N201220-001

Per-Beam Laser Power

0 0.5 1 1.5 2
Time (ns) 0 1 2 3 4

DRACO pre-shot
3.8 ns

Yields were the same ~4.5e13; DRACO predicted 001 ~9e13, 002 ~5e13; shape improvements translate to expected improvement in yield – post-shot simulations suggest laser imprint
Upcoming experiments will test a new flexible color/port-mapping capability to more effectively mitigate CBET in PDD using wavelength detuning.

Current color/port-mapping (symmetric about the equator)

Options for flexible color/port-mapping

Bi-color hemispheric

Tri-color (example)

Design: J. Marozas (LLE)

<table>
<thead>
<tr>
<th>fC2Pm Config</th>
<th>North→Eq</th>
<th>Eq→South</th>
<th>$f_{abs}$ (%)</th>
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<tbody>
<tr>
<td>Bi-color</td>
<td>RRRR</td>
<td>BBBB</td>
<td>Pending</td>
</tr>
<tr>
<td>Tri-color Var#1</td>
<td>GBBB</td>
<td>RRGG</td>
<td>79.1</td>
</tr>
<tr>
<td>Tri-color Var#3</td>
<td>BBGG</td>
<td>RRGG</td>
<td>82.1</td>
</tr>
</tbody>
</table>

*$\Delta \lambda = \pm 4.5$ A (633/638 nm)
Solid spheres are completely impervious to imprint and provide an isolated test of energy coupling and CBET modeling.

Solid sphere radiography platform design

Laser drive:
(8x10^{14} \text{ W/cm}^2 \text{ intensity})

Experiment PI: W. Theobald
Designer: R. Bahukutumbi
Shock trajectory inferred from radiographs and x-ray flash time are in good agreement with 2D DRACO simulations

Experiment PI: W. Theobald
Designer: R. Bahukutumbi

Additional experiments will scan laser intensity and test modeling. Scaled versions of these experiments are planned for...
Laser imprint experiments are conducted on NIF to benchmark models and develop mitigation techniques.

Planar Imprint Platform

Spherical Imprint Platform

Experimental PI: M. Hohenberger (LLNL), M. Rosenberg
Theory PI: A. Shvydky

Experimental PI: M. Karasik (NIF)
Theory PI: A. Shvydky

Ultimate goal is to set requirements for laser and/or target solutions for imprint mitigation (how much/what is needed?)
Planar single-beam imprint experiments have produced excellent data for imprint calculations – a discrepancy is observed (depending on analysis).

Analysis: M. Hohenberger (LLNL), J. Peebles, L. Antonelli (York)
Simulations: A. Shvydky

Sidelighting was developed to validate modeling.
Imprint mitigation using multi-FM SSD on 1 quad was demonstrated in planar geometry.

Preimposed modulation

Experiment/analysis: M. Hohenberger (LLNL)
Simulations: A. Shvydky

A next step for the imprint campaign may be the use of Fresnel zone plate imaging to achieve ~5 µm resolution (vs. 15 µm now)
Cone-in-shell imprint experiments are assessing imprint from multiple overlapping beams and testing high-Z overcoats.

- 400 Å Au coating or uncoated
- Early beam for soft x-ray prepulse to expand the coating 200J, at -10ns

Experiments/analysis: M. Karasik (NRL)
Design: A. Shvydky

Reduced growth of ~20-50 µm; further analysis is ongoing.

MJDD Campaign – what have we learned so far?

- **Energy coupling/symmetry/CBET**: symmetry and energy coupling can be controlled through wavelength detuning, shell contouring, and beam pointing
  - *Next steps*: test flexible color/port-mapping wavelength detuning, solid sphere experiments to benchmark modeling at different intensities/# of shocks

- **LPI/preheat**: SRS is the predominant hot electron source; preheat is close to tolerance levels for intensity $\sim 10^{15}$ W/cm²; Si layers are an effective mitigation strategy
  - *Next steps*: experiments to aid extrapolation of preheat in ignition-scale cryoplant

- **Laser imprint**: we have two good platforms for studying imprint and imprint mitigation; multi-FM SSD and high-Z coatings have some effect
  - *Next steps*: Benchmarking 3D calculations of imprint; higher imaging resolution and other target solutions for imprint mitigation?
Outline

- Laser direct-drive inertial confinement fusion
  - Scaling and motivation for NIF experiments
- MJDD experiments on NIF
  - LPI/hot electron preheat
  - Laser energy coupling/CBET/PDD symmetry
  - Laser imprint
- Current high-yield PDD implosions and pathway to MJ yield
Current high-yield PDD implosions (“exploding pushers”) are conducted with the LLE/LLNL Neutron Sources Working Group, and have routinely produced yields...

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<td>N190227-001</td>
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<td>3.7</td>
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<td>29</td>
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<td>8</td>
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<td>N210213-001</td>
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<td>4.6</td>
<td>5</td>
<td>23</td>
<td>45</td>
<td>6</td>
</tr>
<tr>
<td>Next shot</td>
<td>1.9</td>
<td>450</td>
<td>5.0</td>
<td>5</td>
<td>28</td>
<td>90</td>
<td>8</td>
</tr>
</tbody>
</table>

Experiments: C. Yeaman
Designs: G. Kemp (LLNL)

Near-term goal: $2 \times 10^{16}$ (~50 kJ)

Yeaman et al. Nuclear Fusion 61, 046031 (2021)
Near-term improvement in wavelength detuning (flexible color/port mapping in LID) will facilitate better energy coupling and performance in PDD implosions.

Current color/port-mapping (symmetric about the equator)

Options for flexible color/port-mapping

Bi-color hemispheric

Tri-color

Balanced tri-color

Flexible color/port-mapping is helpful, but significant gain and yield will only be realized when wavelength detuning is > ±3 Å UV (currently limited to ±2.3 Å UV)

Design: J. Marozas
Proposed NIF facility improvements go hand-in-hand with steps to improve convergence and implosion performance (i.e. yield)

1) Current NIF
   • Low-convergence (CR≤10) implosions ("exploding pushers")
   • Physics goal: optimize symmetry in current NIF, validate codes
   • Yield: 50 kJ (~2e16)

2) Flexible color/port-mapping, ±6 Å UV, and PDD phase plates (~mid-2020s)
   • Low-convergence (CR≤10) implosions ("exploding pushers")
   • Physics goal: improve symmetry, absorption >85%
   • Yield: 100 kJ (~4e16)

3) PDD cryogenic target system, beam smoothing (~late 2020s)
   • Warm and cryogenic ablative-driven implosions (CR~15-20)
   • Physics goal: increased compression, alpha heating, burning
   • Yield: 300 kJ (~1e17) to 1 MJ (~4e17)
New diagnostics will contribute to improved understanding, e.g. scattered light diagnostics (SLTD) at a variety of angles.

SLTD schedule:

- 1 SLTD unit: April 2018
- 6 SLTD units: August 2019
- 11 SLTD units: January 2021
- 15 SLTD units: Late 2021

SLTD suite will constrain modeling of scattered light angular distributions and facilitate inference of total scattered light in direct-drive experiments.

Summary/Conclusions

Current MJ-scale experiments lay the groundwork for high-yield direct-drive implosions on the NIF in the 2020’s

- Extrapolation of direct-drive implosion performance from OMEGA to ignition scale on dedicated physics experiments at NIF scale

- The MegaJoule Direct Drive (MJDD) campaign on NIF includes three primary physics programs:
  1) **Hot electron preheat** has been measured at close to tolerable levels, partially mitigated using mid-Z layers, and shown to originate from stimulated Raman scattering
  2) **Implosion symmetry and energy coupling** (including cross-beam energy transfer) has been controlled with wavelength detuning, contoured shells, and beam pointing
  3) **Laser imprint** experiments have produced x-ray radiography data to benchmark models and probe imprint-related instabilities and partial mitigation with multi-FM SSD or high order

- Current NIF capabilities limit high-performance polar-direct drive (PDD) implosion convergence exploding pushers

A staged set of proposed facility improvements will allow for increased convergence