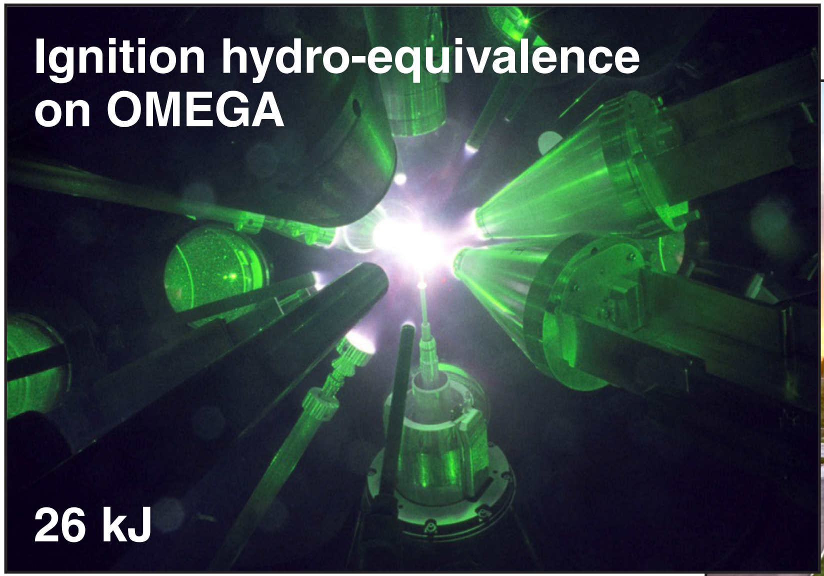
Direct Drive 2020



Ignition hydro-equivalence on OMEGA

26 kJ

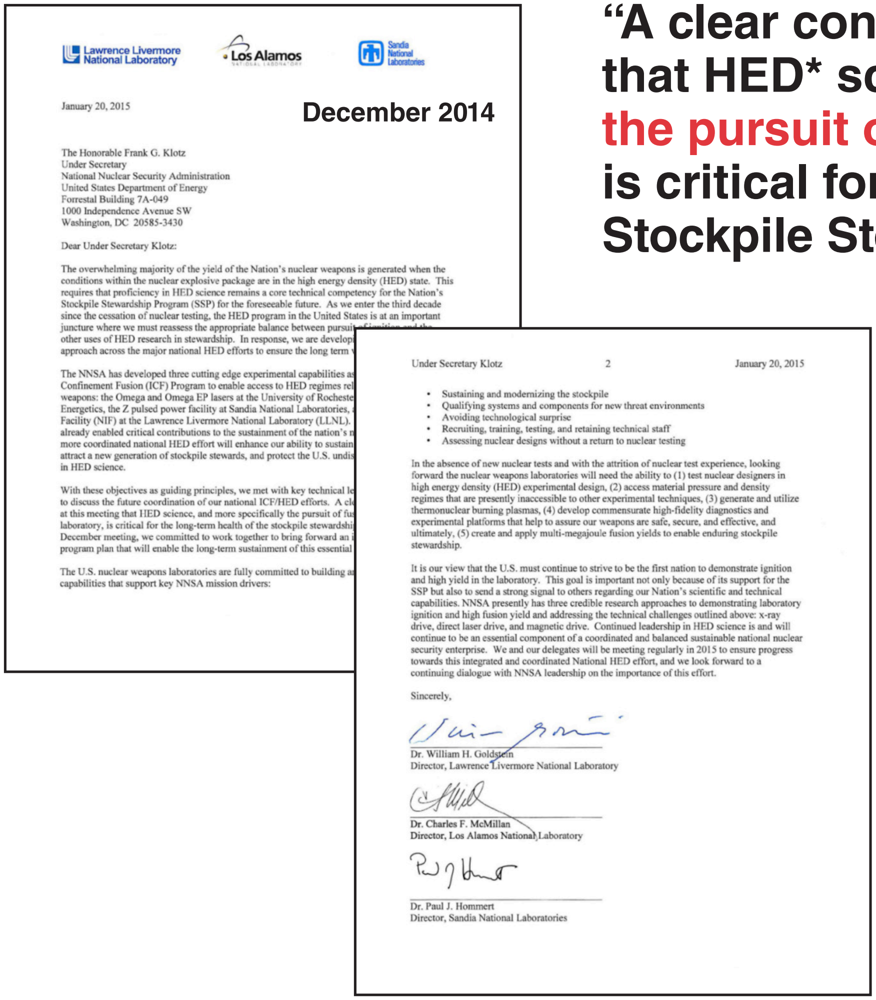
1.8 MJ

Verify laser–plasma interaction scaling at the National Ignition Facility

T. C. Sangster
University of Rochester
Laboratory for Laser Energetics

Omega Laser Facility
Users Group Workshop
Rochester, NY
27–29 April 2016

The tri-lab Directors' letter reinforces the urgency to comprehensively examine all three ignition approaches



December 2014

Lawrence Livermore National Laboratory Los Alamos National Laboratory Sandia National Laboratories

January 20, 2015

The Honorable Frank G. Klotz
Under Secretary
National Nuclear Security Administration
United States Department of Energy
Forrestal Building 7A-049
1000 Independence Avenue SW
Washington, DC 20585-3430

Dear Under Secretary Klotz:

The overwhelming majority of the yield of the Nation's nuclear weapons is generated when the
conditions within the nuclear explosive package are in the high energy density (HED) state. This
requires that proficiency in HED science remains a core technical competency for the Nation's
Stockpile Stewardship Program (SSP) for the foreseeable future. As we enter the third decade
since the cessation of nuclear testing, the HED program in the United States is at an important
juncture where we must reassess the appropriate balance between pursuit
other uses of HED research in stewardship. In response, we are developi
approach across the major national HED efforts to ensure the long term

The NNSA has developed three cutting edge experimental capabilities as
Confinement Fusion (ICF) Program to enable access to HED regimes rel
weapons: the Omega and Omega EP lasers at the University of Rocheste
Energetics, the Z pulsed power facility at Sandia National Laboratories,
Facility (NIF) at the Lawrence Livermore National Laboratory (LLNL).
already enabled critical contributions to the sustainment of the nation's
more coordinated national HED effort will enhance our ability to sustain
attract a new generation of stockpile stewards, and protect the U.S. undis
in HED science.

With these objectives as guiding principles, we met with key technical le
to discuss the future coordination of our national ICF/HED efforts. A cl
at this meeting that HED science, and more specifically the pursuit of fus
laboratory, is critical for the long-term health of the stockpile stewardshi
December meeting, we committed to work together to bring forward an
program plan that will enable the long-term sustainment of this essential

The U.S. nuclear weapons laboratories are fully committed to building a
capabilities that support key NNSA mission drivers:

Under Secretary Klotz 2 January 20, 2015

- Sustaining and modernizing the stockpile
- Qualifying systems and components for new threat environments
- Avoiding technological surprise
- Recruiting, training, testing, and retaining technical staff
- Assessing nuclear designs without a return to nuclear testing

In the absence of new nuclear tests and with the attrition of nuclear test experience, looking forward the nuclear weapons laboratories will need the ability to (1) test nuclear designers in high energy density (HED) experimental design, (2) access material pressure and density regimes that are presently inaccessible to other experimental techniques, (3) generate and utilize thermonuclear burning plasmas, (4) develop commensurate high-fidelity diagnostics and experimental platforms that help to assure our weapons are safe, secure, and effective, and ultimately, (5) create and apply multi-megajoule fusion yields to enable enduring stockpile stewardship.

It is our view that the U.S. must continue to strive to be the first nation to demonstrate ignition and high yield in the laboratory. This goal is important not only because of its support for the SSP but also to send a strong signal to others regarding our Nation's scientific and technical capabilities. NNSA presently has three credible research approaches to demonstrating laboratory ignition and high fusion yield and addressing the technical challenges outlined above: x-ray drive, direct laser drive, and magnetic drive. Continued leadership in HED science is and will continue to be an essential component of a coordinated and balanced sustainable national nuclear security enterprise. We and our delegates will be meeting regularly in 2015 to ensure progress towards this integrated and coordinated National HED effort, and we look forward to a continuing dialogue with NNSA leadership on the importance of this effort.

Sincerely,

Dr. William H. Goldstein
Director, Lawrence Livermore National Laboratory

Dr. Charles F. McMillan
Director, Los Alamos National Laboratory

Dr. Paul J. Hommert
Director, Sandia National Laboratories

"A clear consensus emerged at this meeting that HED* science, and more specifically the pursuit of fusion yield in the laboratory, is critical for the long-term health of the Stockpile Stewardship Program"

"NNSA** presently has three credible research approaches to demonstrating laboratory ignition and high fusion yield"

"It is our view that the U.S. must continue to strive to be the first nation to demonstrate ignition and high yield in the laboratory"

Wait a minute, what do you mean by comprehensively examine?!?

---

*HED: high-energy-density
**NNSA: National Nuclear Security Administration

Comprehensive examination means resource allocation is based on science requirements for each approach

- **Laser direct drive** performs the most shots per year (300 to 400), but most are at the 26-kJ scale
  - even the few tens of shots at the National Ignition Facility (NIF) are at a reduced scale and with limited capability (beam conditioning, spot profiles, diagnostics)
- **Magnetic direct drive** has by far the fewest shot opportunities, but the Z scale is closer to the ignition scale (Z300) and some aspects of magnetized liner inertial fusion (MagLIF) can be tested at scale (e.g., laser preheat on the NIF)
  - see talk by J. Davis Thursday, 28 April on laser-based "mini" MagLIF experiments on OMEGA
- **Laser indirect drive** intends to explore the most options (hohlraum and ablator combinations), but has ~160 shots per year at or near scale on the NIF and another ~100 support shots per year at OMEGA
- The resource balance is currently skewed in favor of laser indirect drive (operations, diagnostics, targets)

The FY15 Review led to an agreement on how to proceed with the ignition approaches for the next five years: *achieve ignition or understand what it will take to do so.*

Summary

The National Direct-Drive Program (DD2020) will inform a decision on whether to reconfigure the NIF for direct drive

- DD2020 followed from the 2012 Path Forward research plan that led to the demonstration of P_{hs} exceeding 50 Gbar
  - knowledge gaps in modeling, target quality, and laser capability were identified
  - an integrated experimental campaign (IEC) to address the knowledge gaps was completed in the spring of 2015
  - a set of focused experiments were developed to address laser–plasma interaction (LPI) related to the IEC
  - new capabilities were identified to address gaps with the target and laser performance
  - national collaborators were asked to help
- The process used for the successful 50-Gbar Campaign has been applied to develop the 100-Gbar (OMEGA) and the MJ Direct-Drive (NIF) Campaigns
- The knowledge gaps are more challenging for scaled ignition implosions
  - what causes the performance cliff for convergence ratios above 17?
  - what causes the observed variation in fuel ρR and T_i?
  - are these correlated with residual kinetic energy (RKE)?
  - why is the scattered light not well predicted during the rise of the main pulse?
- Based on the knowledge gaps, the initial phases of the 100-Gbar and MJ Campaigns will identify needed capabilities and establish IEC's

Participation in the DD2020 will likely become international in 2016

K. S. Anderson, R. Betti, T. R. Boehly, R. Boni, M. Bonino, E. M. Campbell, D. Canning, D. Cao, T. J. B. Collins, R. S. Craxton, A. K. Davis, J. A. Delettrez, W. R. Donaldson, D. H. Edgell, R. Epstein, C. J. Forrest, D. H. Froula, V. Yu. Glebov, D. R. Harding, M. Hohenberger, S. X. Hu, H. Huang, I. V. Igumenshchev, R. T. Janezic, D. W. Jacobs-Perkins, J. Katz, R. L. Keck, J. Kelly, T. J. Kessler, B. E. Krushwitz, J. P. Knauer, T. Z. Kosc, S. J. Loucks, J. A. Marozas, F. J. Marshall, A. V. Maximov, R. L. McCrory, P. W. McKenty, D. T. Michel, S. F. B. Morse, J. F. Myatt, P. M. Nilson, J. C. Puth, P. B. Radha, B. S. Rice, M. J. Rosenberg, T. C. Sangster, W. Seka, W. T. Shmayda, R. Short, A. Shvydky, M. J. Shoup III, S. Skupsky, A. A. Solodov, C. Sorce, S. Stagnitto, C. Stoeckl, W. Theobald, J. Ulreich, M. D. Wittman, B. Yaakobi, and J. D. Zuegel
University of Rochester
Laboratory for Laser Energetics

J. A. Frenje, M. Gatu Johnson, R. D. Petrasso, H. Sio, and B. Lahmann
Plasma Science and Fusion Center, MIT

M. A. Barrios, P. Bell, D. K. Bradley, D. Callahan, A. Carpenter, D. T. Casey, J. Celeste, M. Dayton, S. N. Dixit, C. Goyon, O. A. Hurricane, S. LePape, L. Masse, P. Michel, J. D. Moody, S. R. Nagel, A. Nikroo, R. Nora, L. Pickworth, J. E. Ralph, H. G. Rinderknecht, R. P. J. Town, D. P. Turnbull, R. J. Wallace, and P. J. Wegner
Lawrence Livermore National Laboratory

M. Farrell, A. Greenwood, T. Hilsabeck, J. D. Kilkenny, N. Rice, and M. Schoff
General Atomics

N. Petta and J. Hund
Schafer Corporation

S. P. Obenschain, J. W. Bates, M. Karasik, A. J. Schmitt, and J. Weaver
Naval Research Laboratory

M. J. Schmitt
Los Alamos National Laboratory

G. Rochau, J. Porter, M. Sanchez, L. Claus, G. Robertson, and Q. Looker
Sandia National Laboratories

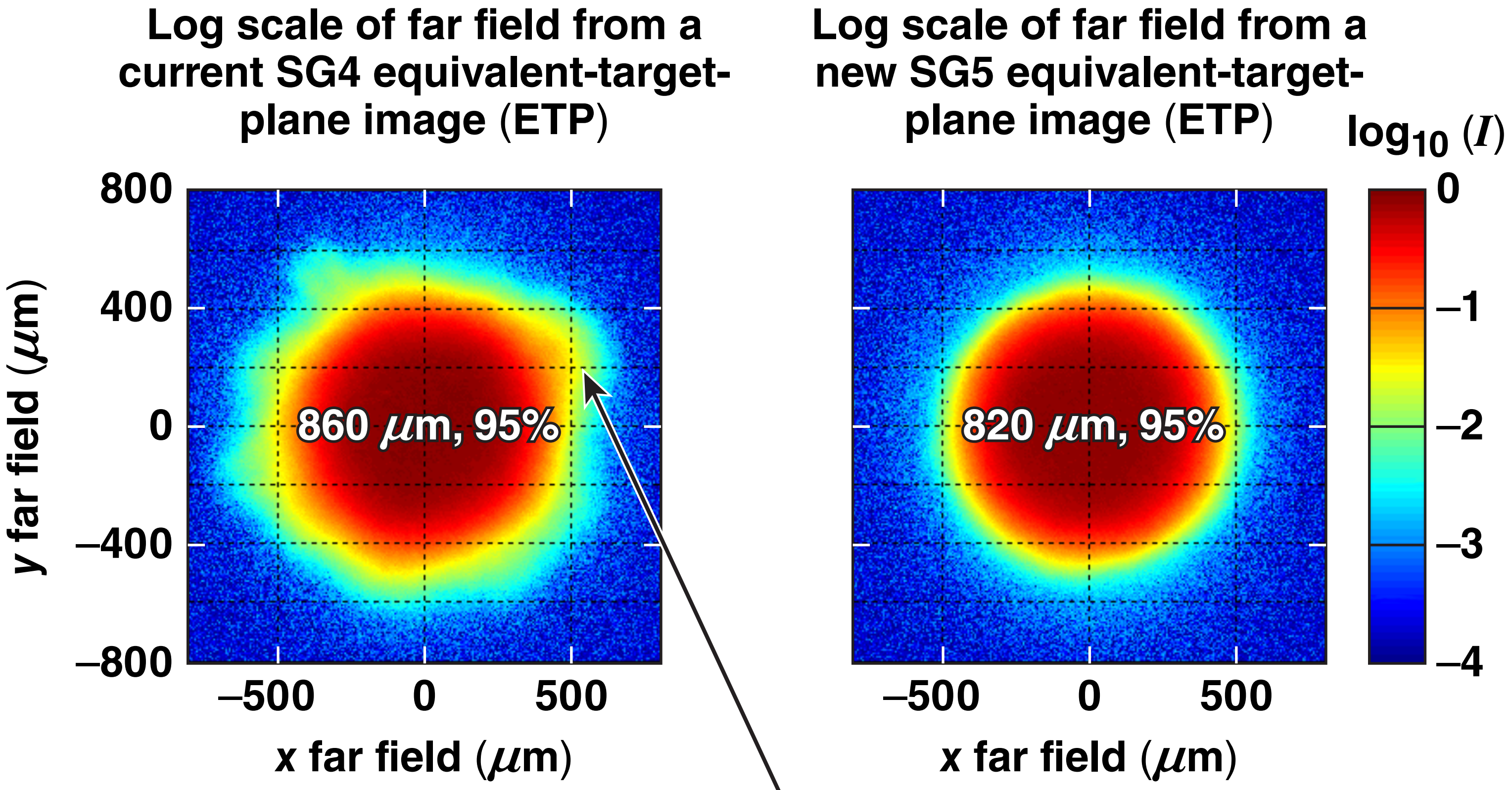
J. Hares and T. Dymoke-Bradshaw
Kentech Instruments ltd.

The successful *science-based* Path Forward 50-Gbar Campaign is the model for the new 100-Gbar Campaign

- The Direct-Drive Path Forward activity identified knowledge gaps and capability requirements that led to routine $P_{hs} > 50$ Gbar
- Design/modeling
  - Cross-beam energy transfer (CBET) and preheat modeling [laser-plasma simulation environment (*LPSE*) developed; Omega Laser Facility Users Group (OLUG) 2017]
  - first-principles equation-of-state (FPEOS) (CH; OLUG 2017)
  - thermal-transport modeling (2-D)
- Laser
  - new set of SG5 phase plates (820-μm spot, 95% encircled)
  - multipulse driver line to enable dynamic bandwidth reduction (up to 10% more energy on target)
- Target
  - the new Isotope Separator System (ISS) purified the DT fuel and the isotopic ratio was restored to 50:50 in the void
- Diagnostics
  - new 16-channel high-temporal (30-ps) and high-spatial (6-μm)-resolution Kirkpatrick–Baez microscope (KBframed)
  - new neutron temporal diagnostic (NTD) with 40-ps response and a signal-to-background (S/B) exceeding 100
  - "precision neutron time-of-flight (nTOF)" for more-accurate ion temperatures

Implosion drive uniformity was improved using a new set of phase plates [fabricated using magnetorheological finishing (MRF)]

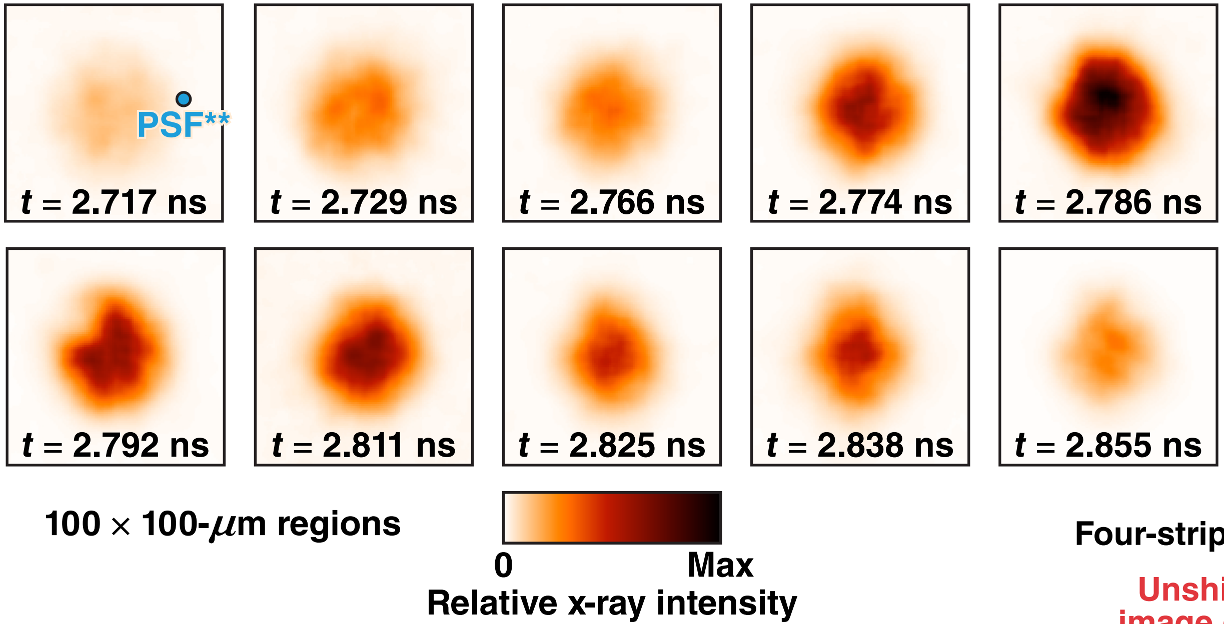
$$I \sim \exp\left[\left(-r/r_0\right)^{n}\right]$$



Light that seeds CBET is eliminated; overlap uniformity is improved.

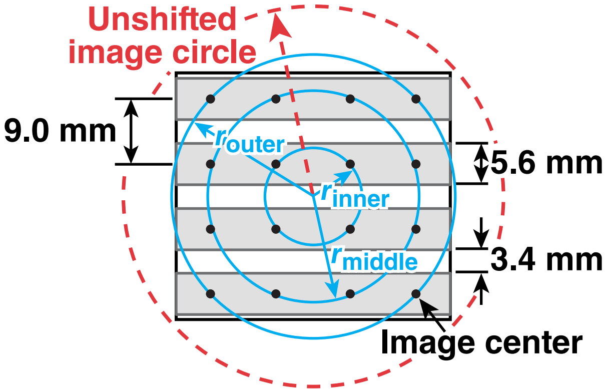
The 16-channel KBframed measures the evolution of the hot-spot radium during the burn*

OMEGA cryogenic DT target implosion, shot 76828



Optic assembly

Four-strip framing-camera schematic



The Laboratory for Laser Energetics (LLE) expects to duplicate the KBframed in the FY17–FY18 time frame.

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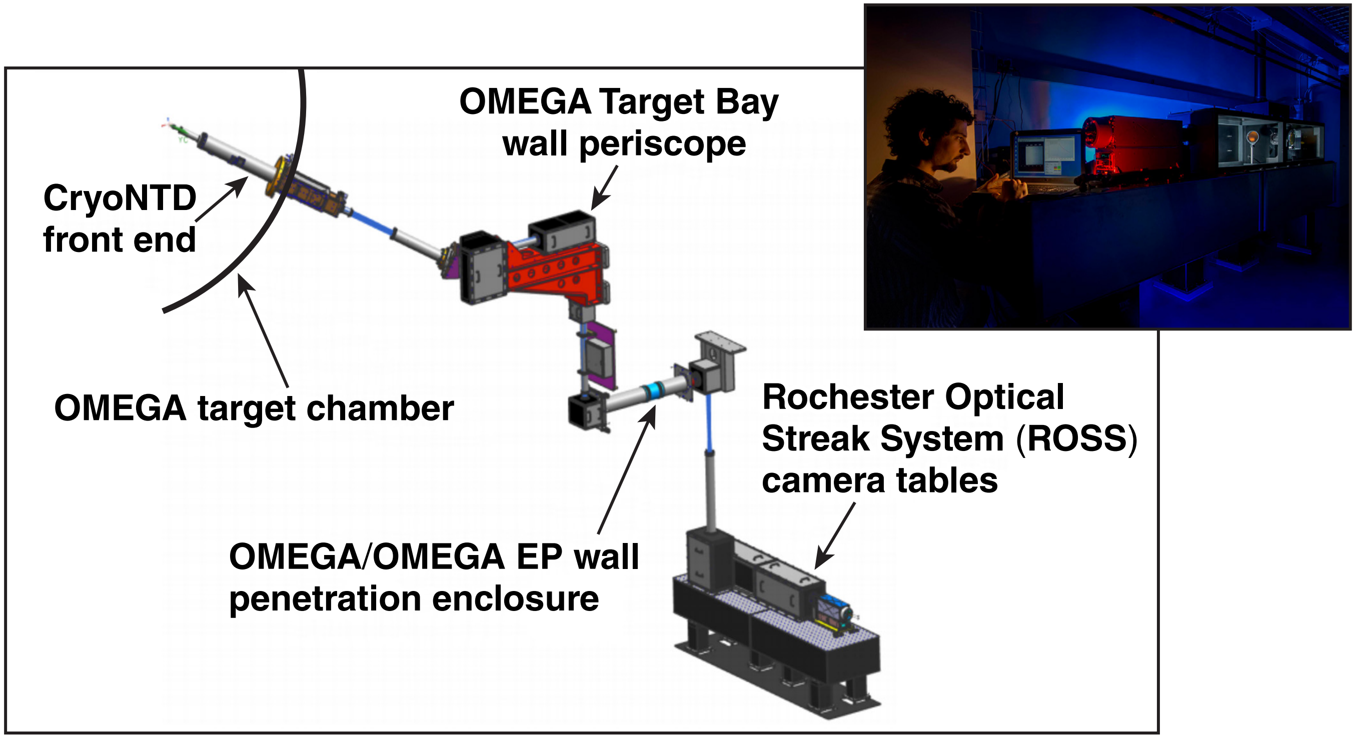
* F. J. Marshall, Rev. Sci. Instrum. 83, 10E518 (2012).

** PSF: point-spread function

The new P11-NTD measures the bang and confinement (burnwidth) times



CryoNTD front end

OMEGA Target Bay wall periscope

OMEGA target chamber

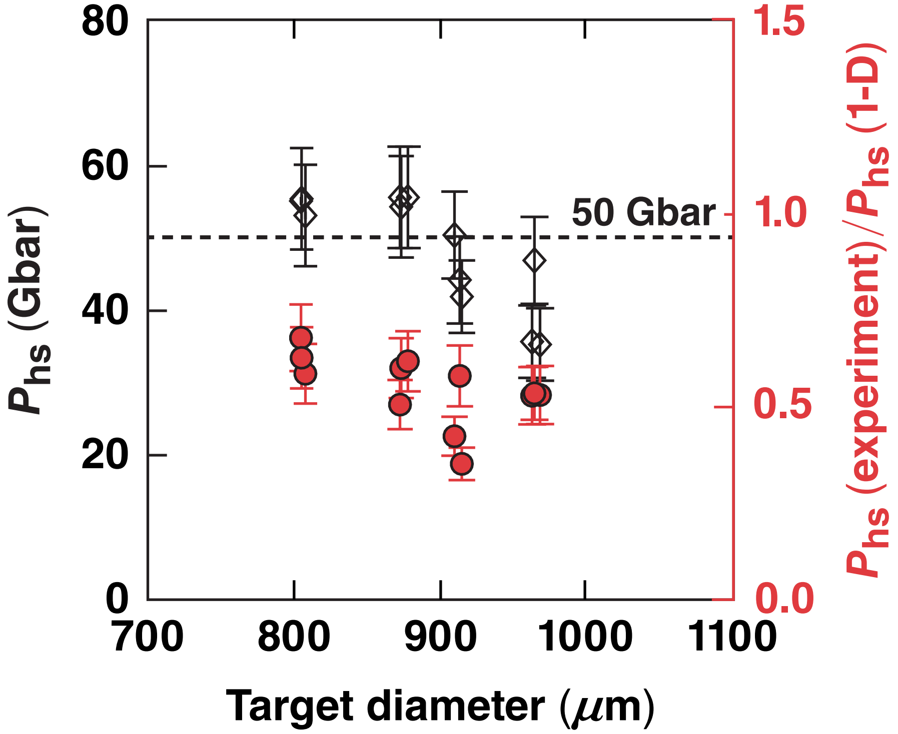
Rochester Optical Streak System (ROSS) camera tables

OMEGA/OMEGA EP wall penetration enclosure

Performance metric	Performance status
Impluse response function	40±10 ps
Absolute timing	±25 ps, ±50 ps
Precision	±5 ps
S/B	>100
DT yield range	5 × 10^{10} to 1 × 10^{15}

Despite a decrease in CBET with larger targets, the hot-spot pressure remained at only ~50% of the 1-D prediction

The FY15 Q3 campaign used a variety of capsule outside diameters with a fixed laser spot size to study coupling efficiency and CBET mitigation.

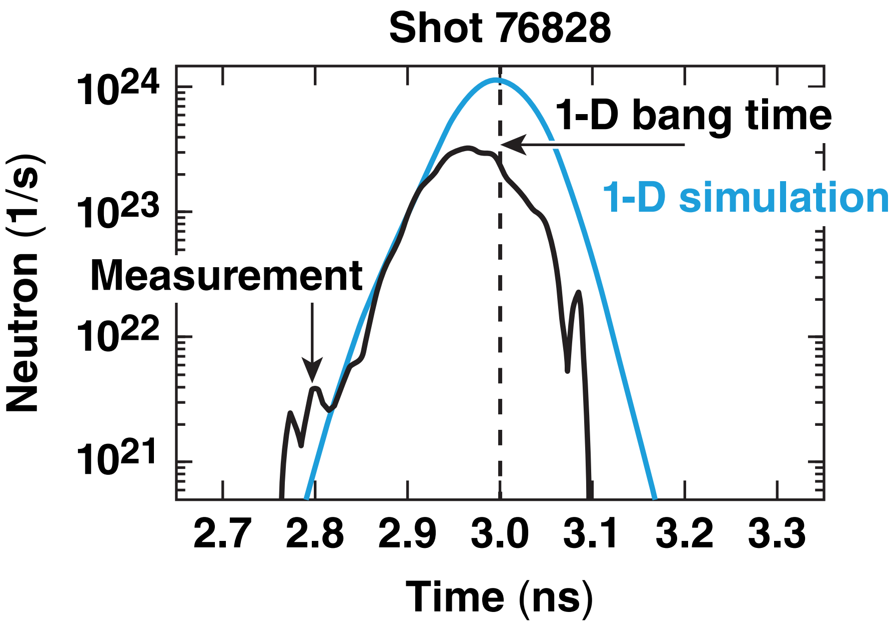


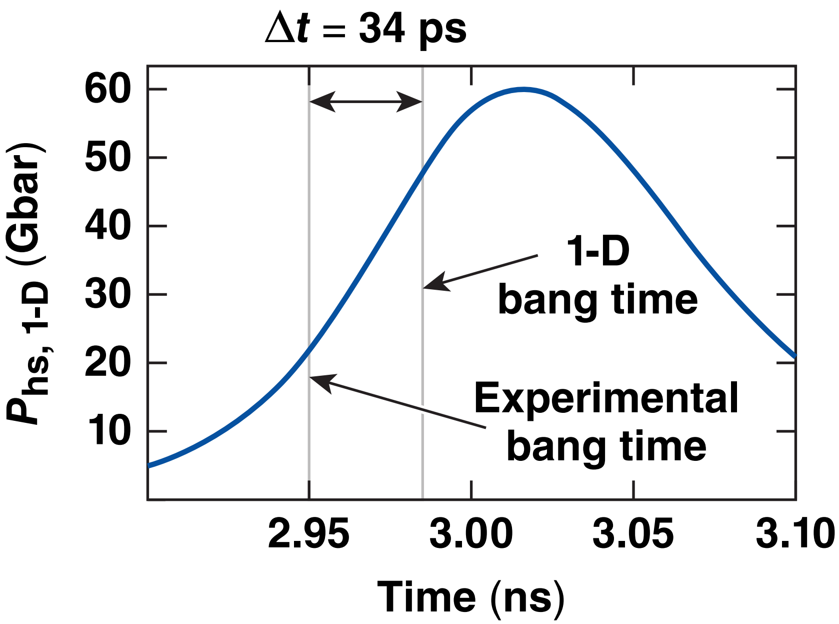
LILAC includes 2-D ray trace, nonlocal conduction, and CBET

Knowledge gap: ***Why does the pressure appear to fall with increasing CBET mitigation?!***

Hypothesis: Low-mode ($\ell = 2\pi R/\lambda < 5$) laser drive nonuniformity limits the hot-spot pressure.

Comparing the neutron-reaction history with prediction suggests burn truncation prior to stagnation



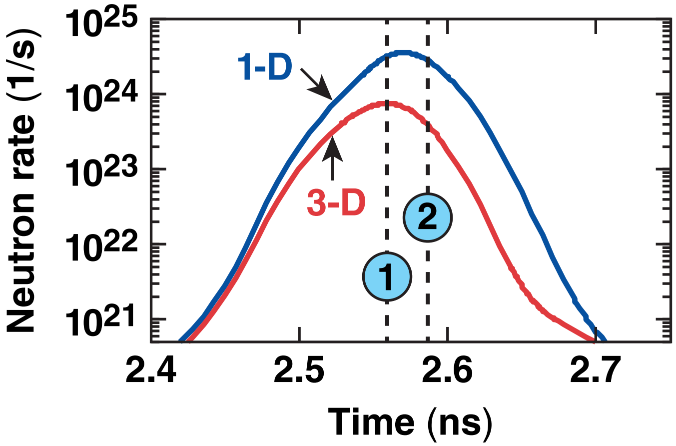


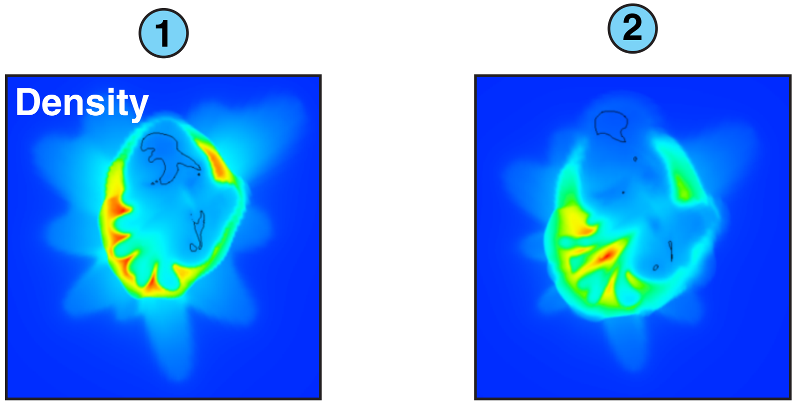
A shift in the temporal sampling region by tens of picoseconds can make a significant difference in the inferred pressure and fuel ρR.

TC12324c

Three-dimensional simulations predict burn truncation because of long-wavelength drive nonuniformity growth in the shell

Simulations using the new *ASTER** hydrocode at LLE

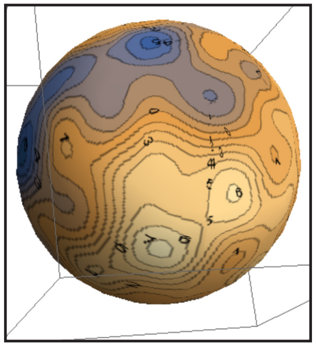




1-D:
No perturbations
P_{hs} (t_{bang}) ~ 93 Gbar

3-D:
10-μm offset,
15% rms power balance
10-μm rms pointing
P_{hs} (t_{bang}) ~ 47 Gbar

Illumination nonuniformity
3-D solid-sphere projection



These simulations motivate stricter requirements on the laser power balance!

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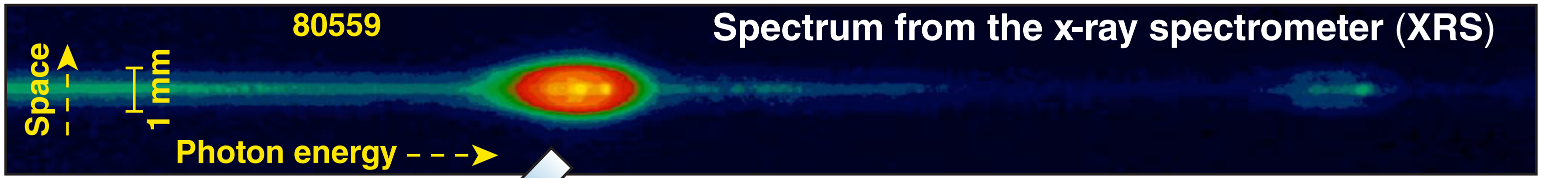
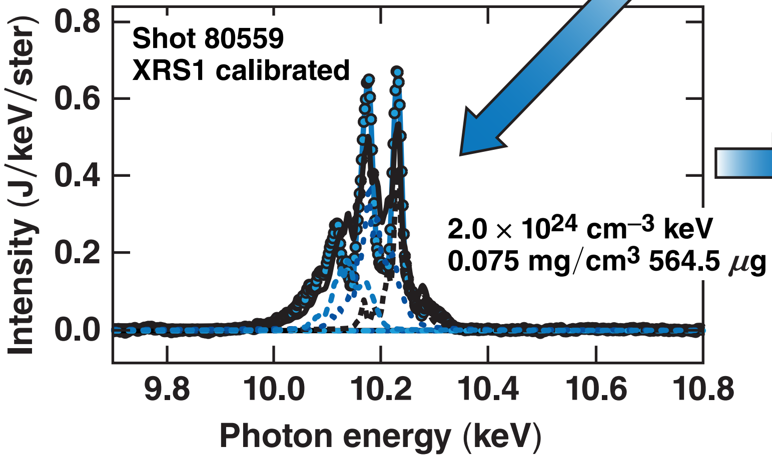
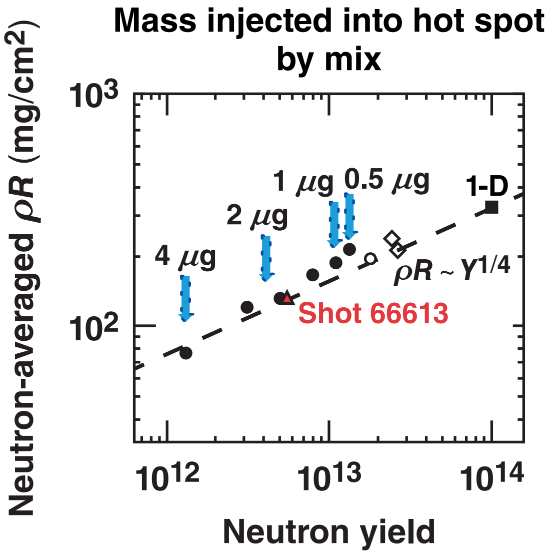
*I. V. Igumenshchev *et al.*, "Three-Dimensional Modeling of Direct-Drive Cryogenic Implosions on OMEGA," to be published in Physics of Plasmas.

Mass injected into the hot spot in recent Ge-doped ablator-layered DT implosions is consistent with prediction*





Preliminary fit: 0.6 μg of ablator is mixed into the hot spot



Relative to non-doped implosions:

- Yield is lower by ~2×
- Absolute core emission is ~2× higher
- T_i is significantly lower
- Bang time is ~50 ps earlier
- Core size is significantly larger
- Burn duration is longer

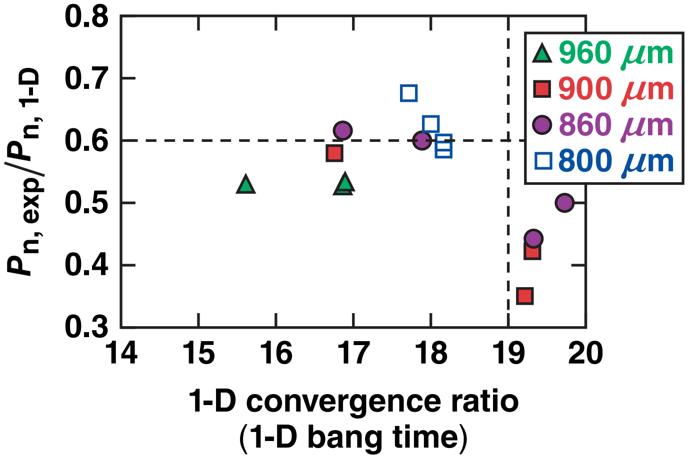
These new results (further) motivate improvements to the capsule surface quality!

---

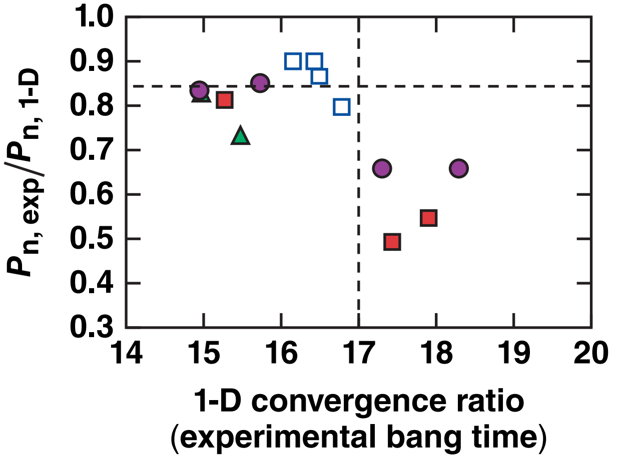
*I. V. Igumenshchev *et al.*, Phys. Plasmas 20, 082703 (2013).

When measured burn truncation is included, the 1-D prediction agrees with the inferred P_{hs} and ρR for convergence ratio (CR) < 17 and $\alpha > 3.5$

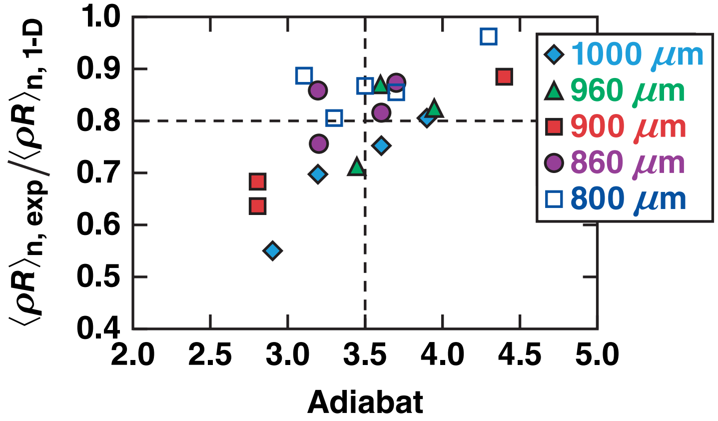
1-D pressure at 1-D peak burn



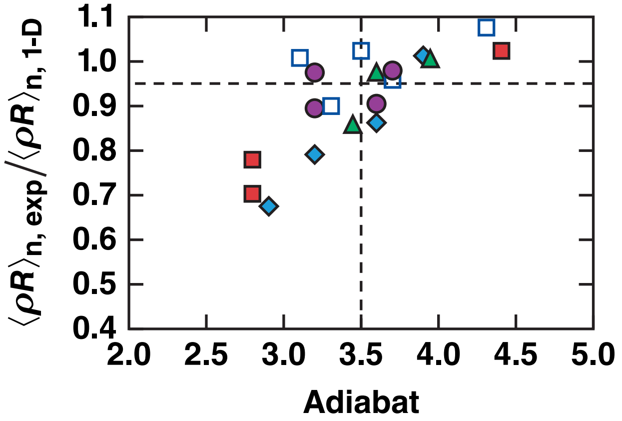
1-D pressure at experimental peak burn



1-D pressure averaged over 1-D burn

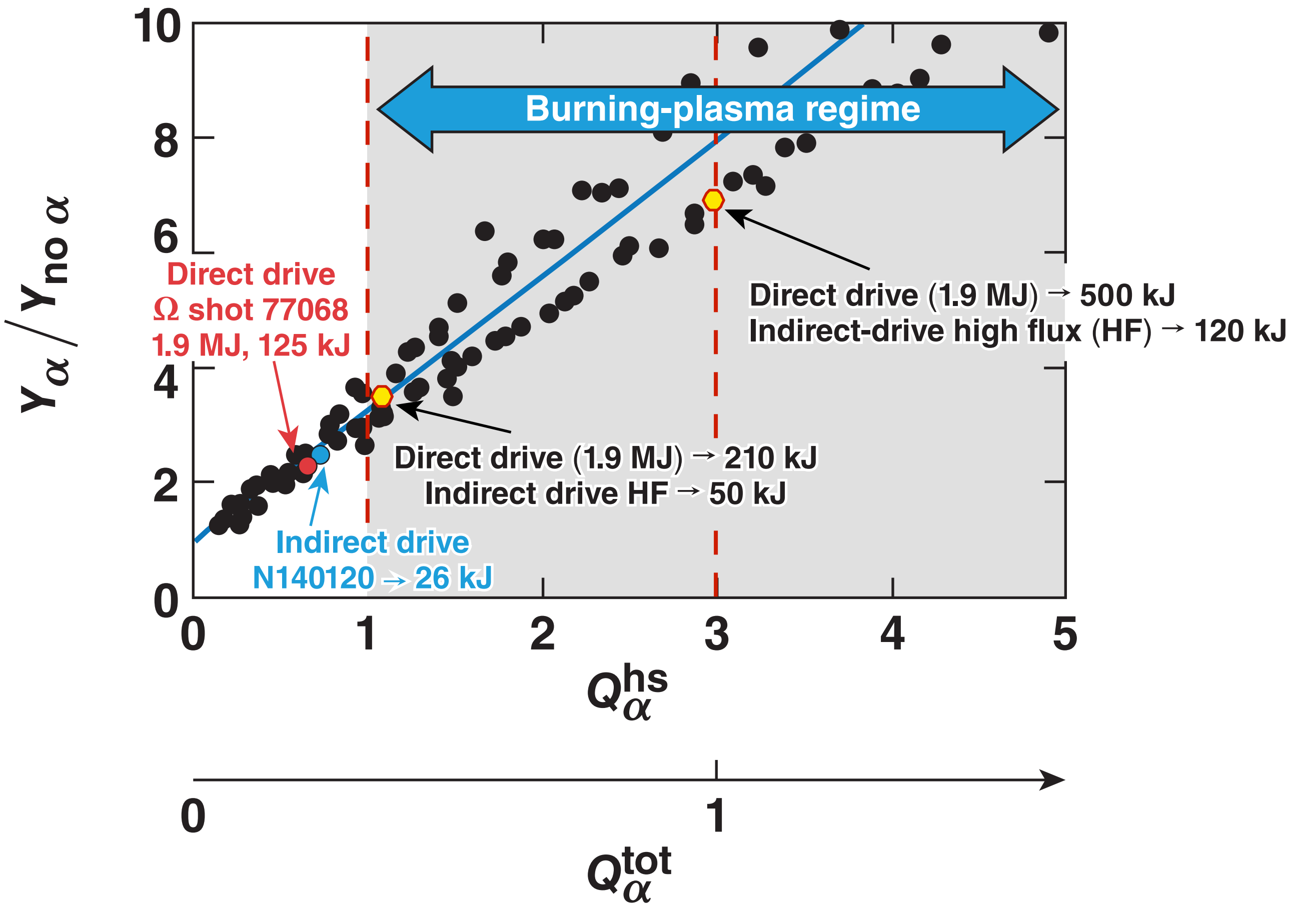


1-D ρR averaged over experiment burn
(with burn truncation)



TC12326a

Hydro-equivalent scaling of the OMEGA 56-Gbar implosions extrapolates to an α amplification of ~2



Direct drive
Ω shot 77068
1.9 MJ, 125 kJ

Indirect drive
N140120 → 26 kJ

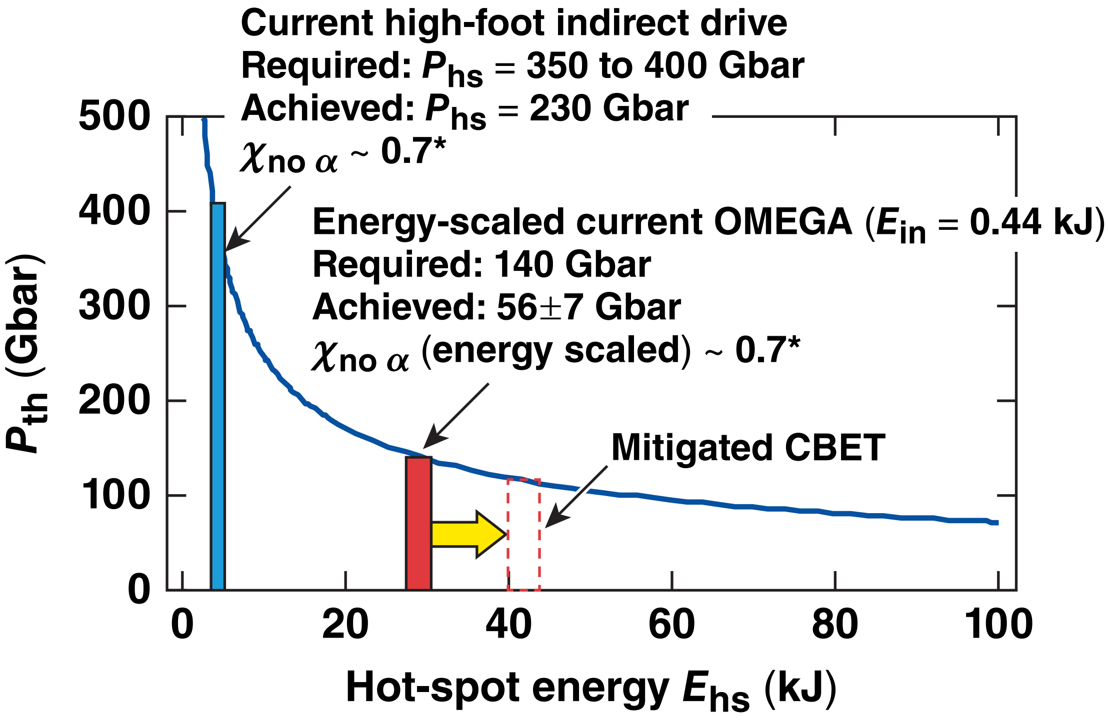
Direct drive (1.9 MJ) → 210 kJ
Indirect drive HF → 50 kJ

Direct drive (1.9 MJ) → 500 kJ
Indirect-drive high flux (HF) → 120 kJ

Similar scaling of a 100-Gbar pressure would lead to a yield of ~1 MJ.

The 100-Gbar goal will demonstrate that most knowledge gaps have been filled (*at the OMEGA scale*)

We know that the hot-spot pressure must exceed a threshold value to ignite



Current high-foot indirect drive
Required: $P_{hs} = 350$ to 400 Gbar
Achieved: $P_{hs} = 230$ Gbar
$\chi_{\text{no }\alpha} \sim 0.7$*

Energy-scaled current OMEGA ($E_{in} = 0.44$ kJ)
Required: 140 Gbar
Achieved: 56±7 Gbar
$\chi_{\text{no }\alpha}$ (energy scaled) ~ 0.7*

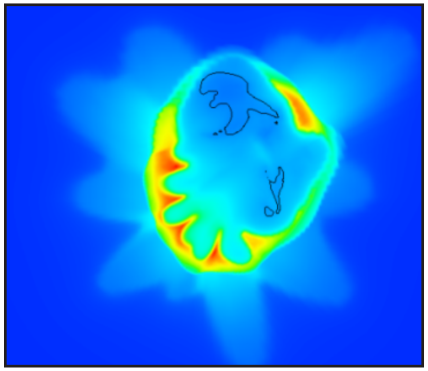
Mitigated CBET

$$\frac{P_{hs}}{P_{th}} = \left(\frac{P_{hs}}{250\ \text{Gbar}}\right)\sqrt{\frac{E_{hs}}{10\ \text{kJ}}} > 1$$

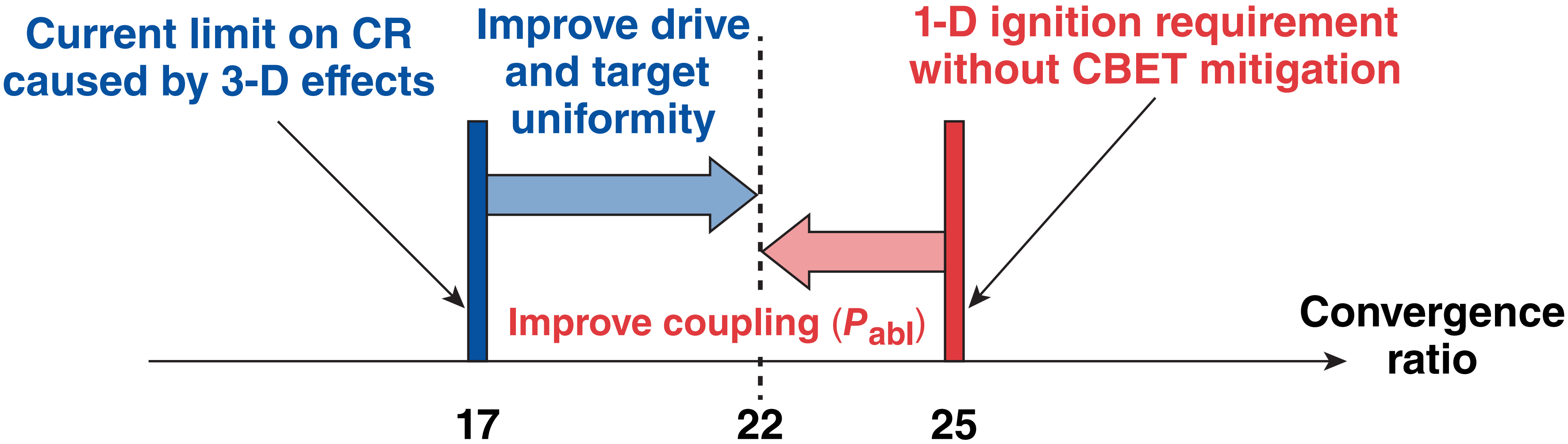
$$P_{hs} \sim E_{hs}^{-1/2} \sim E_{fuel}^{-1/2}$$

Important to note that hot-spot pressures achieved with indirect drive far exceed what is needed for direct-drive ignition and gain.

CR is an amplifier for all of the target and drive imperfections (lower CR_{ign} is good!)



$$CR_{ign} \sim \left[E_k^{1/6} V_{imp}^{2/3} \left(\frac{P_{abl}}{\alpha}\right)^{1/5}\right]^{-1} \sim \left[\left(\frac{E_L V_{imp}}{I}\right)^{1/6} P_{abl}^{1/2}\, \mathrm{IFAR}^{1/3}\right]^{-1}$$



Current limit on CR caused by 3-D effects

Improve drive and target uniformity

1-D ignition requirement without CBET mitigation

Improve coupling (P_{abl})

Convergence ratio

17

22

25

Indirect drive CR_{ign} ~ 35 to 40

Indirect drive claims to have near 1-D performance for CR ~ 25, a good omen for direct drive.

IFAR: in-flight aspect ratio

The DD2020 has four components

- Hydro-equivalent implosions on OMEGA
  - the 100-Gbar Campaign will identify physics knowledge gaps and implement the laser, target, and diagnostic requirements
  - intermediate goal of 80 Gbar with reduced requirements
  - pressure-relief devices (PRD's): coupling, preconditioning, implosion, and stagnation and burn
  - IEC's: cryo, cbet beamlets, decompression, CZGrowth, AltAblat,...
- LPI control, energy coupling, and imprint mitigation with MJ-scale plasmas on the NIF
  - the MJ Direct-Drive Campaign will address LPI understanding/control and mitigation strategies at the ignition scale
  - PRD's: coupling, preconditioning
  - IEC's: dλ_DDShap, AltAbl_DDShap
- Strategy for the conversion of the NIF to spherical direct drive (SDD)
  - cost, schedule, and phasing
- Robust target designs for a range of performance and applications
  - hot-spot ignition
  - shock ignition
  - alpha heating and gain
  - double shells

LLE is a partner in the National Diagnostics Plan.

What are the current knowledge gaps?

- CR performance cliff for CR > 17
- Equation of state (EOS) (CH, DT, Si, Au, Pd, and compound ablators)
- Coronal physics (e.g., hot electrons and scattered light for high $d\lambda/dt$)
- Thermal transport (conduction zone, nonlocal modeling, 3-D)
- CBET modeling (polar versus symmetric, speckles, 3-D, …)
- CBET mitigation [e.g., bandwidth ($\Delta\lambda$) and two-state zooming]
- Measurement of RKE and mitigation
- Variations in fuel ρR and T_i
- Imprint mitigation via high-Z layers, dopants, foams, …
- 1-D physics [50% yield-over-clean (YOC) for $\alpha \sim 7$!]
- Capsule surface quality at shot time
- Capsule bulk properties following an ~200-Mrad dose
- DT ice density and uniformity at shot time
- …

The 100-Gbar Campaign has eight work breakdown structure (WBS) elements addressing laser, target, modeling, and measurement requirements

Campaign leads: S. Regan and V. Goncharov

WBS elements	Leads	Goals
Laser power balance	J. Kelly	Implement laser capability for 1% to 3% rms; improve beam pointing and timing
Fill-tube target	D. Harding and B. Rice	Develop concepts for fill-tube–based targets and an insertion system
Laser upgrades for CBET mitigation	T. Kessler and D. Froula	Develop zooming and bandwidth options for CBET mitigation
Implosion modeling and simulation	P. McKenty	Improve physics and ray tracing in *HYDRA*, *DRACO*, *ASTER*, *LILAC*, and *RAGE*
1-D implosion physics	R. Betti	Design and modeling to explain non-1-D performance of "stable" implosions
Laser–plasma interactions	J. Myatt and D. Froula	Develop models and options for CBET, two-plasmon decay (TPD), and stimulated Raman scattering (SRS) mitigation strategies
Shock timing	T. Boehly	Understand coupling and shock strength via the coalescence of multiple shocks
Diagnostics	W. Theobald and C. Sorce	Instrumentation shell physics, hot-spot characterization, and LPI understanding

Significant development is needed to meet the laser requirements for the 100-Gbar Campaign

80 Gbar (CH)

- On-target power balance of 3% rms over 100-ps intervals
- Beam pointing <10-μm rms and stable during a shot day
- Beam timing <5-ps rms and stable during a shot day (and measurable within an hour)
- Dozens of tasks have been identified for the power-balance effort including
  - optimize frequency-conversion crystals (FCC's) tuning
  - optimize use of P510 dynamic range
  - understand distributed polarization rotator (DPR) and ultraviolet (UV) polarization effects on UV transport to target
  - understand why autobalance (ABAL) drives the system away from calorimeter–based balance
  - improve infrared (IR) loss measurements
  - 3-GHz amplitude modulation (AM) mitigation (realign P510 fiber launchers)
  - understand differences between the north and south HED cameras during small-signal-gain (SSG) runs
  - fix inequality of near fields in each leg of the A split

100 Gbar (CH/Si/CH)

- On-target power balance of 1% rms over 100-ps intervals
- Implementation of full-aperture zooming and wavelength diversity (to reduce CBET losses)
  - beam-to-beam $\Delta\lambda$
  - stimulated rotational Raman scattering (SRRS)
  - enhanced phase modulation
- Beam pointing per the 80-Gbar spec
- Beam timing per the 80-Gbar spec

This work is motivated by the mix and burn truncation measurements as well as 2-D/3-D modeling.

Significant development is needed to meet the capsule requirements for the 100-Gbar Campaign

80 Gbar (CH)

- Target offset at chamber center: <10 μm
- At shot time:
  - <10 particles of 0.5 to 1.0 μm on the capsule surface and none >1 μm
  - inner surface ablator roughness $<\sigma_{rms} = 0.5$ μm in modes $\ell < 5$ and $\sigma_{rms} = 0.1$ μm in modes $\ell \geq 5$
- At cryogenic temperature:
  - target outside diameter (OD) known to <2 μm
  - target outer-surface nonuniformity ($\ell < 10$) known to <0.1 μm
  - DT ice thickness known to 0.5 μm
  - DT ice density known to <5%.
  - ablator atomic composition and density (C:H:O:D:T) known to <10%

100 Gbar (CH/Si/CH)

- Target offset at chamber center: <5 μm
- At shot time:
  - <10 particles of 0.5 μm on the capsule surface and none >0.5 μm
  - inner surface ablator roughness per the 80-Gbar spec
- At cryogenic temperature:
  - target outer diameter (OD) per the 80-Gbar spec
  - target outer-surface nonuniformity ($\ell < 10$) per the 80-Gbar spec
  - DT ice thickness per the 80-Gbar spec
  - DT ice density per the 80-Gbar spec
  - ablator atomic composition and density (C:H:Si:O:D:T) known to <10%
- Fill-tube capability with glue spot <30 μm
- Phase-contrast imaging for CH/Si/CH

General Atomics (GA) and LLE plan to organize a surface-characterization workshop with industry.

Significant development is needed to meet the modeling requirements for the 100-Gbar Campaign

- Simulate every layered DT implosion on OMEGA with 2-D *DRACO* using CBET and nonlocal transport
- Implement a hot-electron model in 2-D *DRACO*
- Implement 3-D laser direct drive in *HYDRA* including ray trace, CBET and nonlocal transport, and perform low-mode 3-D simulations for selected layered DT implosions
- Develop a first-principles model for CBET (validate against experiments)
- Develop first-principles opacity tables for CH and Si
- Add radiation transport into *ASTER** (new LLE 3-D hydrocode)
- Validate 1-D implosion physics against experiment
- Develop a full-aperture zooming model including beam smoothing to calculate the time-dependent irradiance and power spectrum for the pickets and main pulse

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*I. V. Igumenshchev *et al.*, "Three-Dimensional Modeling of Direct-Drive Cryogenic Implosions," submitted to Phys. Plasmas.

All of the sites are engaged in the DD2020 program

National Direct-Drive Program

	100 Gbar	MJ Direct Drive	DD Design working group (WG)	SDD WG	National diagnostics program (NDP)
Naval Research Laboratory (NRL)	Imprint	Imprint and bandwidth	Design	(O)	
Lawrence Livermore National Laboratory (LLNL)		LPI modeling	DD design and verification	(P)	SLOS* Ω, OTS**
Los Alamos National Laboratory (LANL)	Imprint/opacity		Pushered single shell–double shell (PSS-DS), *RAGE*	(O)	
Sandia National Laboratories (SNL)			(Laser) miniMagLIF	(O)	SLOS Ω
The Laboratory for Laser Energetics (LLE) and MIT	Lead	Lead	*HYDRA*, *RAGE*	(P)	SLOS Ω, OTS, HiRes
General Atomics (GA)	Fill-tubes, Alt Ablator, capsules,…	Cone-in-shell, Alt Ablator, capsules,…			SLOS Ω

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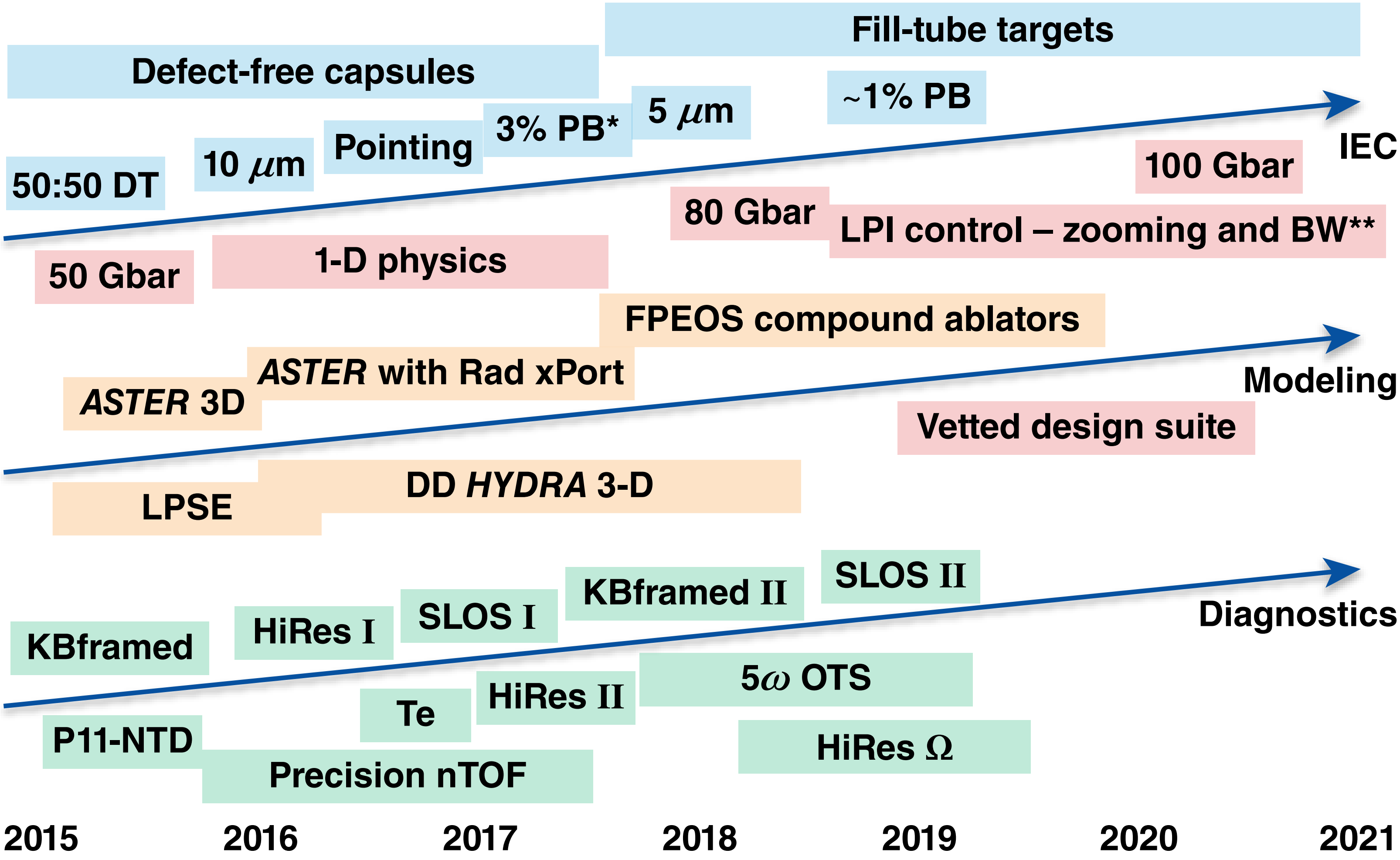
*SLOS: single line of sight

**OTS: optical Thomson scattering

The success of DD2020 will depend on a combination of improved capabilities, better measurements, and modeling



Fill-tube targets

Defect-free capsules

~1% PB

5 μm

3% PB*

Pointing

10 μm

50:50 DT

IEC

100 Gbar

80 Gbar

LPI control – zooming and BW**

50 Gbar

1-D physics

FPEOS compound ablators

ASTER with Rad xPort

ASTER 3D

Modeling

Vetted design suite

DD *HYDRA* 3-D

LPSE

SLOS II

KBframed II

SLOS I

HiRes I

KBframed

Diagnostics

5ω OTS

HiRes II

Te

P11-NTD

HiRes Ω

Precision nTOF

2015 2016 2017 2018 2019 2020 2021

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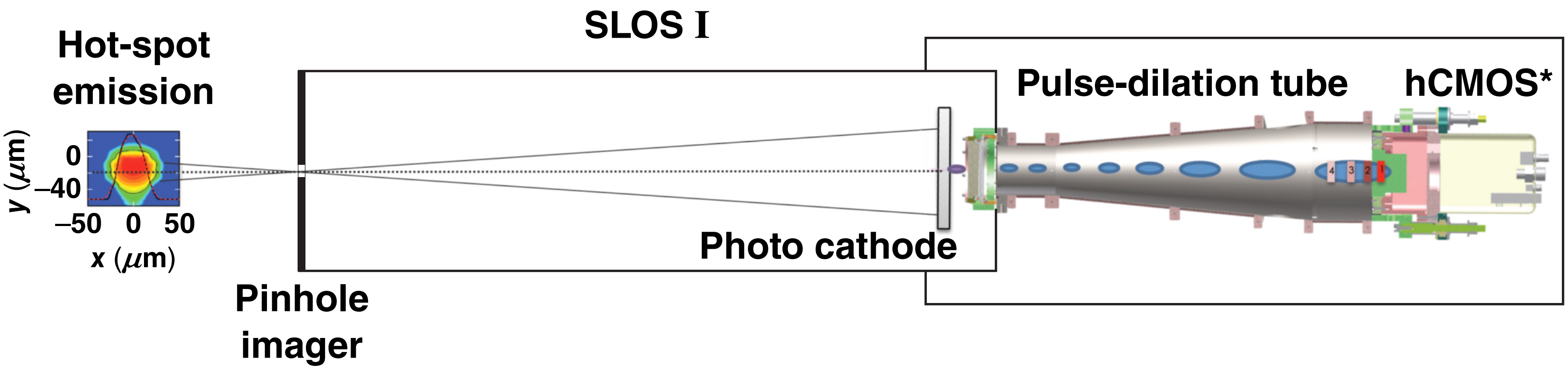
*PB: power balance; **BW: bandwidth

Diagnostics required for the 100-Gbar and MJ Campaigns will leverage the National Diagnostics Plan

An LLE/GA/SNL/LLNL collaboration will install and qualify a SLOS I x-ray imager on OMEGA by early FY17



- Hot-spot image in the 4- to 8-keV photon-energy range
- Temporal resolution ~30 ps
- Four frames to sample ~100-ps burnwidths (cryogenic DT implosions)
- Pinhole provides ~7-μm spatial resolution for a 20-μm hot-spot radius

SLOS II will include higher-resolution optics and temporal recording (<5 μm and 10 ps).

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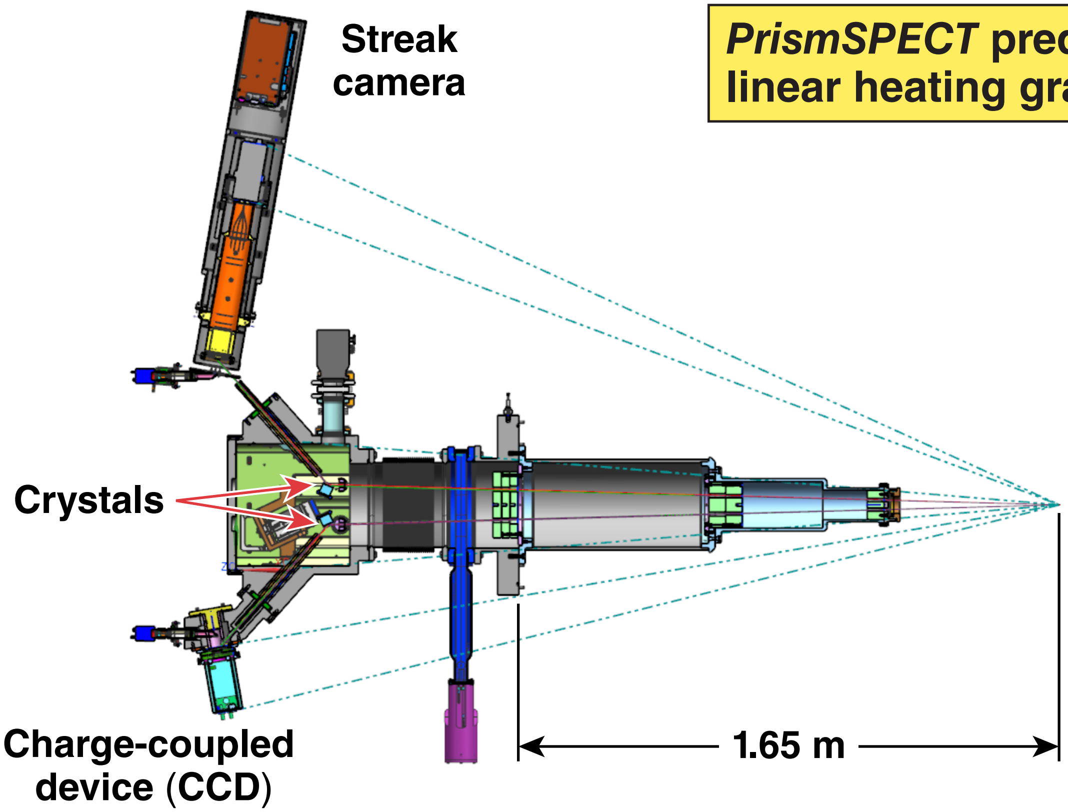
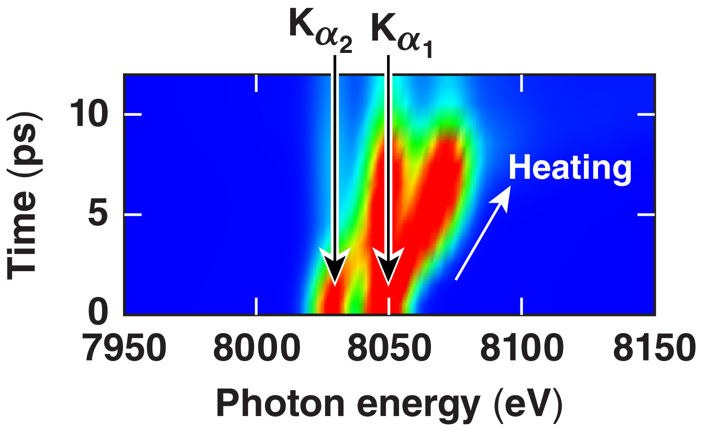
*hCMOS: hybrid complementary metal-oxide semiconductor

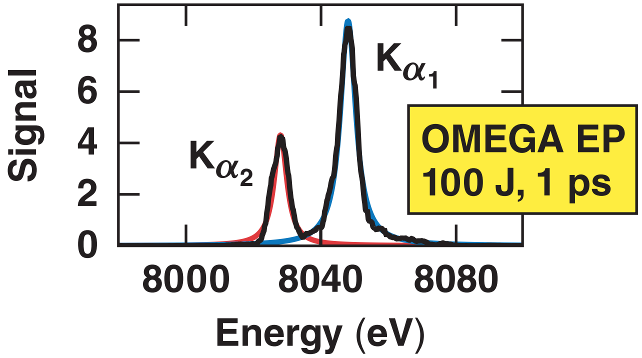
HiRes, developed with Princeton Plasma Physics Laboratory (PPPL), is an ultrafast, high-resolving-power spectrometer for temperature-relaxation studies*



PrismSPECT **prediction for solid density Cu, a linear heating gradient of 350 eV and $E/\Delta E$ ~ 1000.**



First data from OMEGA EP



A streak camera will be deployed for time-resolved emission spectroscopy experiments in Q2FY17… then HiResW.

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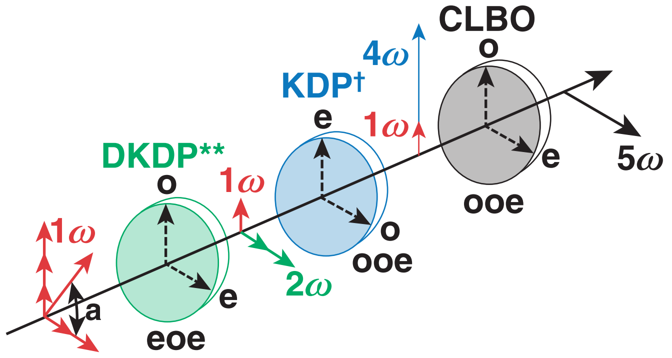
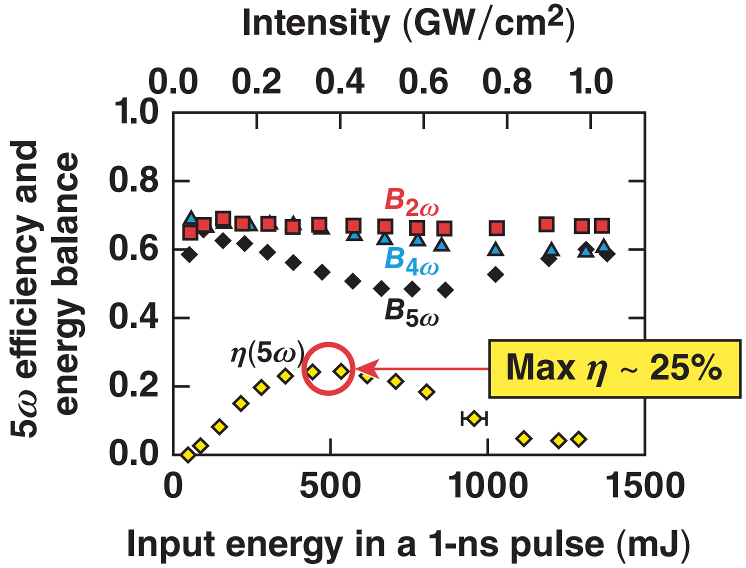
* P. M. Nilson *et al.*, NIF Diagnostic Workshop (2014).

A record fifth-harmonic-generation efficiency (for 211-nm laser pulses) was demonstrated with CLBO*

- Collaboration between LLE and LLNL for an OTS laser
  - LLNL purchased CLBO crystal (30-mm diam) from Coherent
  - LLE added a 5ω test bed to the Multi-Terawatt (MTW) laser
  - PI: I. Begishev (LLE) and P. Datte (LLNL)
- Record performance demonstrated
  - maximum efficiency, η ~ 25%
  - up to 250 mJ for 2.8-ns pulse
- Detailed studies completed
  - optimum pulse width
  - energy balance (B)
  - two-photon absorption
  - polarization angle (a)
  - temperature and angular acceptance

Cascade of three crystals





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*CLBO: cesium lithium borate

**DKDP: deuterated potassium dihydrogen phosphate

†KDP: potassium dihydrogen phosphate

The goal of the MJ Direct-Drive Campaign is to demonstrate LPI control and mitigation at the ignition scale

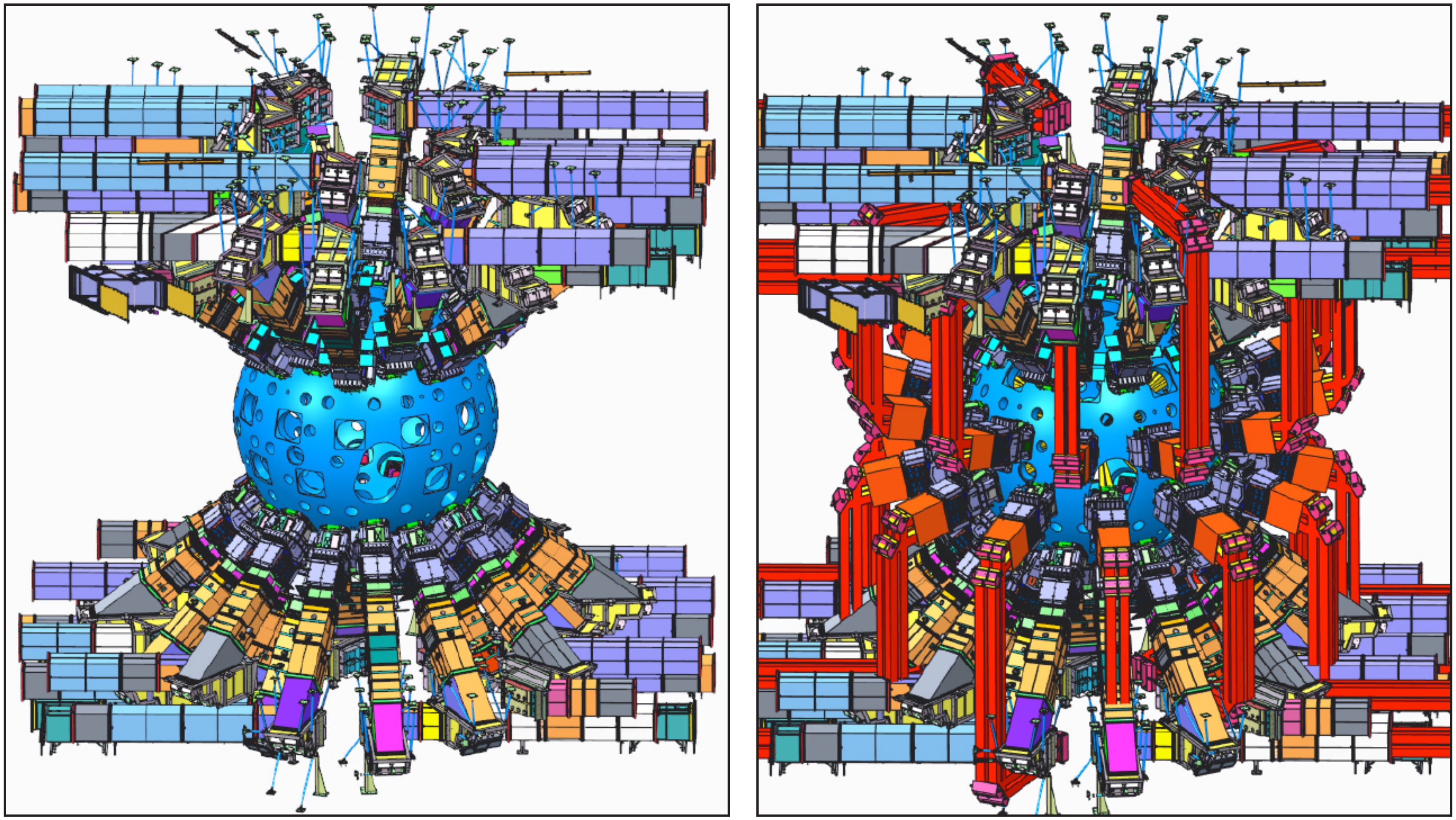
Research	Target Physics (PRD's)	NIF Platforms (so far)
Energy coupling	Driver-target coupling Target preconditioning Implosion Intrinsic and transport properties Modeling validation	**Validation:** Multi-axis, shock-timing polar-direct-drive (PDD) implosions **Mitigation:** Wavelength detuning Multi-ablator implosions
Adiabat	Driver-target coupling Target preconditioning Implosion Intrinsic and transport properties Modeling validation	**Validation:** Multi-axis shock timing Planar TPD PDD implosions **Mitigation:** Multi-Ablator (mid-Z layers) in planar and PDD geometry
Laser imprint	Target preconditioning Implosion Modeling validation	**Validation:** Planar foils Cone-in-shell geometry **Mitigation:** Multi-FM (mFM) smoothing (planar) Doped ablators in planar and PDD geometry

The baseline for LPI modeling and control will be developed with the 100-Gbar Campaign on OMEGA.

LLNL has formed a working group to support SDD ignition target designs for the NIF

- Main goals
  - design and interpretation of NIF planar LPI experiments (3-D *HYDRA*)
  - develop alternate low-gain designs that are more robust than the current "point design" that span the onset of alpha heating to ignition
- Points-of-contact: O. Hurricane (LLNL) and V. Goncharov (LLE)
- Areas of research
  - NIF-scale length LPI (experiment and theory)
    - LLNL: P. Michel (lead) and J. Moody, C. Goyon; LLE: J. Myatt (lead), D. Froula, R. Bahukutumbi, M. Hohenberger, and M. Rosenberg
  - NIF-scale alternate capsule designs spanning ~100 kJ to multi-MJ
    - LLNL: O. Hurricane (lead), L. Masse, M. Tabak, and R. Nora; LLE: T. Collins (lead), P. McKenty, R. Bahukutumbi, V. Goncharov, J. Marozas, and K. Anderson
  - Support development of SDD capability in *HYDRA*
    - LLNL: M. Marinak (lead); LLE: P. Mckenty (lead), J. Marozas, K. Anderson, T. Collins, and D. Cao
  - Explore direct-drive–relevant experiments/designs that use NIF in the indirect-drive configuration
    - LLNL: O. Hurricane (lead), L. Masse, M. Tabak, and R. Nora; LLE: T. Collins (lead), P. McKenty, R. Buhukutumbi, V. Goncharov, J. Marozas, and K. Anderson
  - SDD double-shell designs (to be determind)

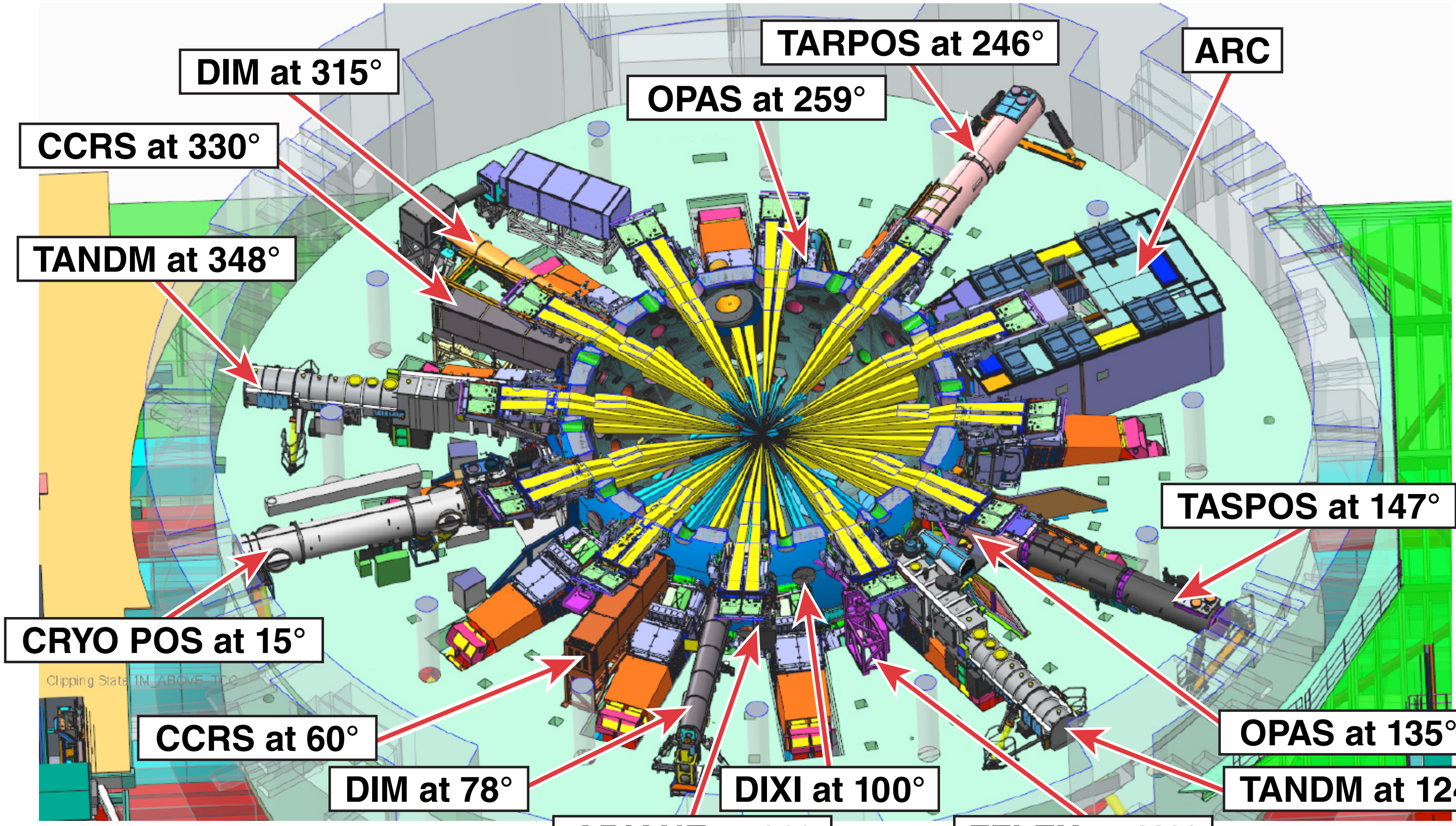
The major scope of the NIF SDD reconfiguration is the relocation of beam transport and final optics



The new locations for the fixed diagnostics, inserts, and manipulators have been identified.

E25009

The equator level of the Target Bay must be cleared to make space for the direct-drive final optics assemblies



TARPOS at 246°

ARC

DIM at 315°

OPAS at 259°

CCRS at 330°

TANDM at 348°

TASPOS at 147°

CRYO POS at 15°

CCRS at 60°

OPAS at 135°

DIM at 78°

DIXI at 100°

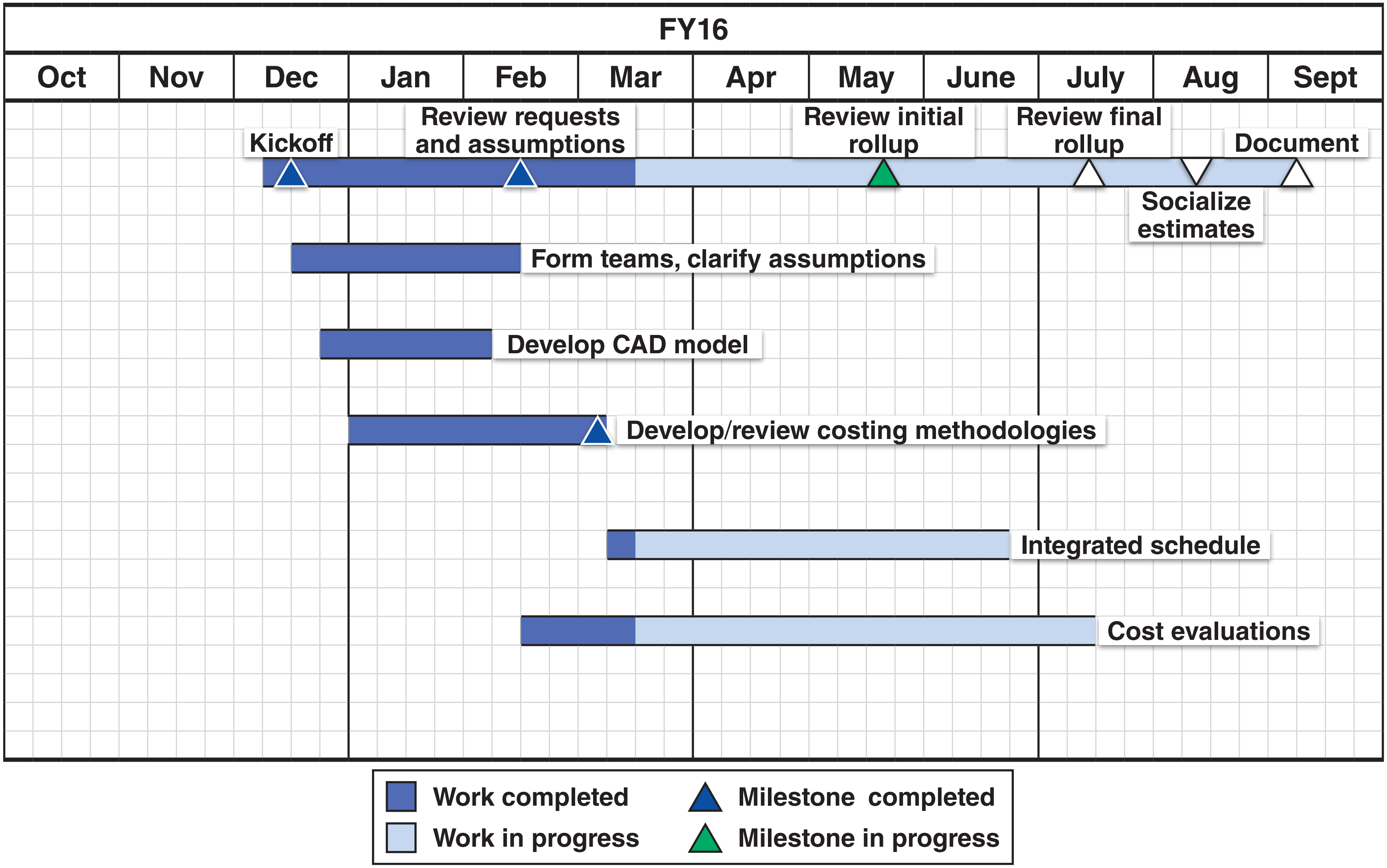
TANDM at 124°

ARIANE at 89°

FFLEX at 110°

DIM: diagnostic instrument manipulator
CCRS: chamber center reference system
TANDM: target and diagnostic manipulator
CRYO POS: cryo positioner
ARIANE: active readout in a neutron environment
DIXI: dilation x-ray imager
FFLEX: filter-fluorescer x-ray diagnostic
OPAS: opposed port alignment system
TASPOS: target positioner
ARC: advanced radiography capability

The goal is to have an initial estimate (cost and schedule) for the major components by the end of FY16



Summary/Conclusions

The National Direct-Drive Program (DD2020) will inform a decision on whether to reconfigure the NIF for direct drive

- DD2020 followed from the 2012 Path Forward research plan that led to the demonstration of P_{hs} exceeding 50 Gbar
    - knowledge gaps in modeling, target quality, and laser capability were identified
    - an integrated experimental campaign (IEC) to address the knowledge gaps was completed in the spring of 2015
    - a set of focused experiments were developed to address laser–plasma interaction (LPI) related to the IEC
    - new capabilities were identified to address gaps with the target and laser performance
    - national collaborators were asked to help
- The process used for the successful 50-Gbar Campaign has been applied to develop the 100-Gbar (OMEGA) and the MJ Direct-Drive (NIF) Campaigns
- The knowledge gaps are more challenging for scaled ignition implosions
    - what causes the performance cliff for convergence ratios above 17?
    - what causes the observed variation in fuel ρR and T_i?
    - are these correlated with residual kinetic energy (RKE)?
    - why is the scattered light not well predicted during the rise of the main pulse?
- Based on the knowledge gaps, the initial phases of the 100-Gbar and MJ Campaigns will identify needed capabilities and establish IEC's

LLE and SNL are working on a coordinated effort to advance the science of MagLIF

- Support of SNL-led heating experiments on OMEGA EP
  - a new sub-aperture backscatter station (SABS) diagnostic will be available for experiments in FY16
  - gas-filled targets required new manifold
  - uses magneto-inertial fusion electrical discharge system (MIFEDS) (10 T)-magneto-inertial fusion
- LLE-led "miniMagLIF" campaign (nine shot days during FY16–FY17)
  - laser-driven integrated "MagLIF" experiments
  - new 3ω heating beam in port P9
  - joint Advanced Research Projects Agency-Energy (ARPA-E) project with SNL
  - uses MIFEDS (10 T)
  - inertial confinement fusion (ICF) shot allocation and ARPA-E procured shot days
- 30-T MIFEDS under development (G. Fiksel)
- Drive design for laser-based MagLIF