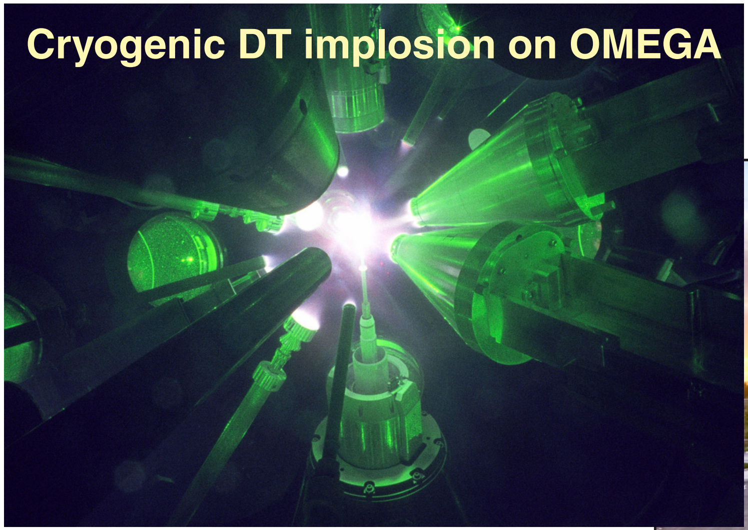
OMEGA Recent Results and Plans

Ignition hydro-equivalence


Cryogenic DT implosion on OMEGA

… and laser–plasma interaction/ symmetry validation

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Fusion Power Associates
35th Annual Meeting
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Summary

Our near-term path forward is to achieve pressures in excess of 50 Gbar on OMEGA

- Near 1-D implosions are being performed at an $\alpha \sim 4$ with $V_{imp} \sim 370$ km/s and inferred $\langle P \rangle_n \sim 37$ Gbar and $P_{peak} \sim 47$ Gbar
- New capabilities are expected to push pressures above 50 Gbar in FY15 and much closer to hydro equivalence in FY16/17
- The first 14 polar-direct-drive (PDD) shots on the National Ignition Facility (NIF) confirm predicted coupling and preheat mitigation
- The Laser Path Forward Working Group is developing the implementation plans for high-performance PDD on the NIF

Our long-time goal is to do layered PDD implosions on the NIF.

Collaborators

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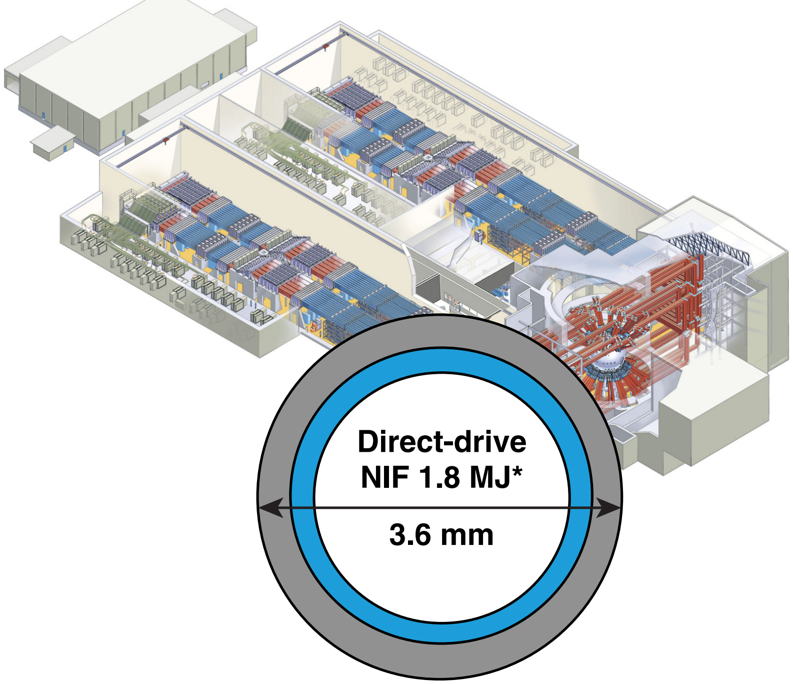
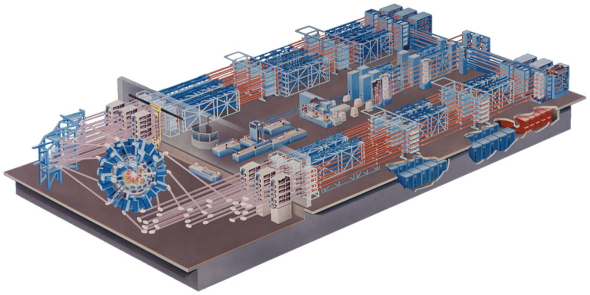
Symmetric direct-drive–ignition designs* can be scaled for hydrodynamic equivalence at the OMEGA scale

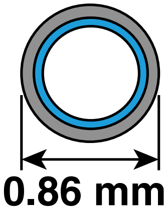
- Hydro-equivalence on OMEGA** is a fuel ρR of 300 mg/cm^2 and a yield of 4×10^{13}





Scale 1:70 in energy

OMEGA 26 kJ



Hydrodynamic scaling

Capsule radius ~ $E_L^{1/3}$
Shell thickness Δ ~ $E_L^{1/3}$
Laser power ~ $E_L^{2/3}$
Pulse length ~ $E_L^{1/3}$
Mass fuel ~ E_L

Performance metrics include $P\tau$ (atm-s), pressure (Gbar), yield, and compressed fuel ρR (g/cm^2)

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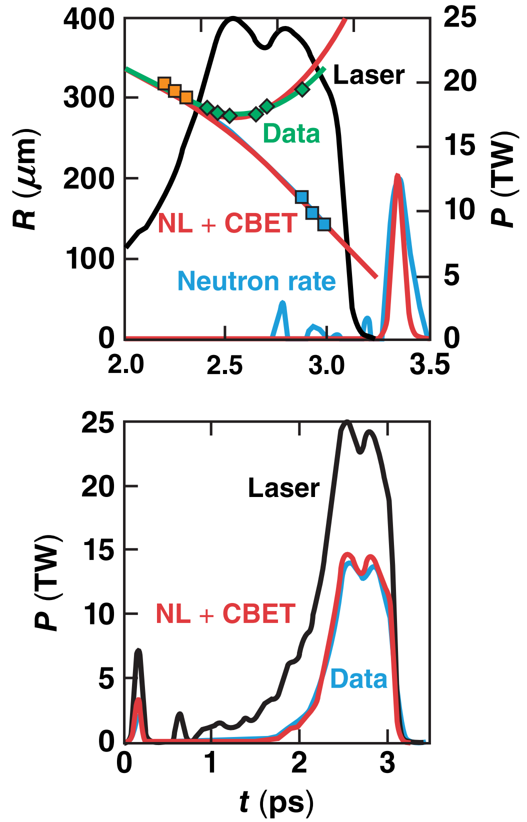
[*] V. N. Goncharov *et al*., Phys. Rev. Lett. 104, 165001 (2010).
[**] R. Betti, presented at the 24th IAEA Fusion Energy Conference, San Diego, CA, 8–13 October 2012.

The PDD Path Forward plan is to predictably increase the pressure with direct drive on OMEGA and understand the experimental results on the NIF

- Increase the central pressure in OMEGA cryogenic DT implosions to (goal is 50 Gbar)
  - this will require some mitigation of cross-beam energy transfer (CBET) and improved laser/target uniformity
- Complete the modeling required to validate energetics and symmetry requirements for ignition-scale PDD experiments
- Experimentally establish symmetry control and test laser–plasma instability (LPI) modeling at near-ignition scale on the NIF
  - improved hydrouniformity requires laser smoothing and dedicated PDD phase plates
- Experimentally demonstrate the predicted single-beam smoothing using 1-D multi-FM smoothing by spectral dispersion (SSD) (FY13 Path Forward milestone)
- Develop full-scale glancing angle deposition (GLAD)-coated optics for polarization rotation
- Develop the technical implementation plans
  - dedicated PDD optics
  - 1-D multi-FM SSD
  - the ignition target insertion cryostat (ITIC)

PDD laser path forward working group is developing the facility upgrade plans.

The physics models in the LLE hydrocodes are being validated against high-quality implosion data on OMEGA



- 1-D *LILAC* simulations that include nonlocal (NL) thermal transport and CBET losses reproduce the measured absorption and shell kinetic energy[*]
- Little evidence for hot-electron preheat; mitigation with mid-*Z* layers[**]
- Hydroefficiency of alternate ablators favors Be[***]
- CBET mitigation will be required for high convergence at modest in-flight aspect ration (IFAR[†]) ("zooming" FY16–FY17)
- $\alpha \sim 4$ implosions at relevant velocities are approaching ideal 1-D performance

The near-term goal for PDD on the NIF is to confirm modeling validated against OMEGA data.

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[*] D. T. Michel *et al*., "Measurements of the Conduction Zone Length and Mass Ablation Rate in Cryogenic Direct-Drive Implosions on OMEGA," to be submitted to Phys. Rev. Lett.

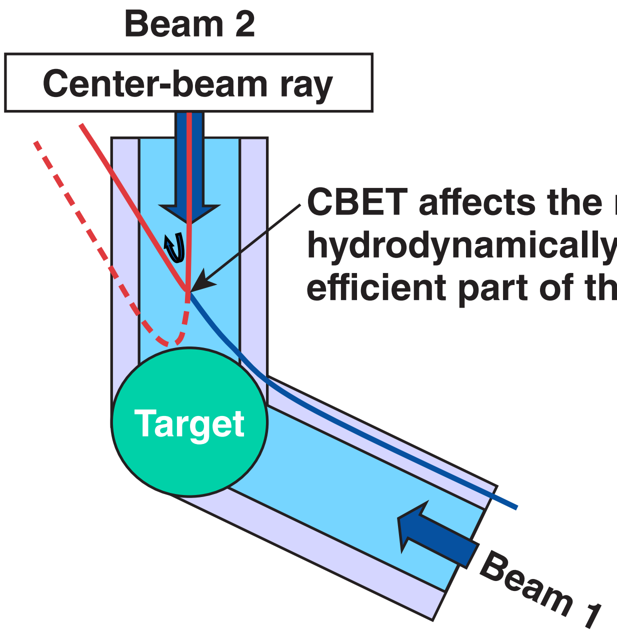
[**] J. F. Myatt *et al*., Phys. Plasmas 20, 052705 (2013).

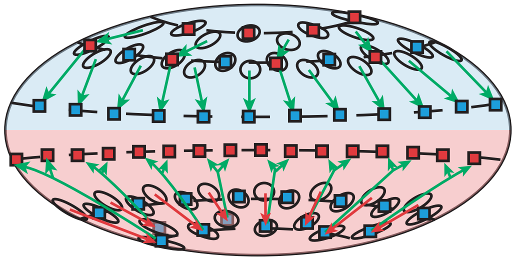
[***] D. T. Michel *et al*., Phys. Rev. Lett. 111, 245005 (2013).

[†] D. H. Froula *et al*., Phys. Plasmas 20, 082704 (2013).

[‡] V. N. Goncharov *et al*., Phys. Plasmas 21, 056315 (2014).

CBET reduces the ablation pressure late in time by up to 50%*





NIF hemispheric wavelength detuning

There are two options for CBET mitigation on OMEGA and the NIF:

- Minimize the light going over the “horizon” of the capsule (best for OMEGA)
    - laser spots underfill the target (SG5)
    - “zooming” changes the laser spot size during the pulse**
- Detune the laser frequencies to minimize the simulated Brillouin scattering (SBS) resonance volume in which CBET occurs (best for the NIF)
    - “hemispheric wavelength detuning”
    - phase-plate design

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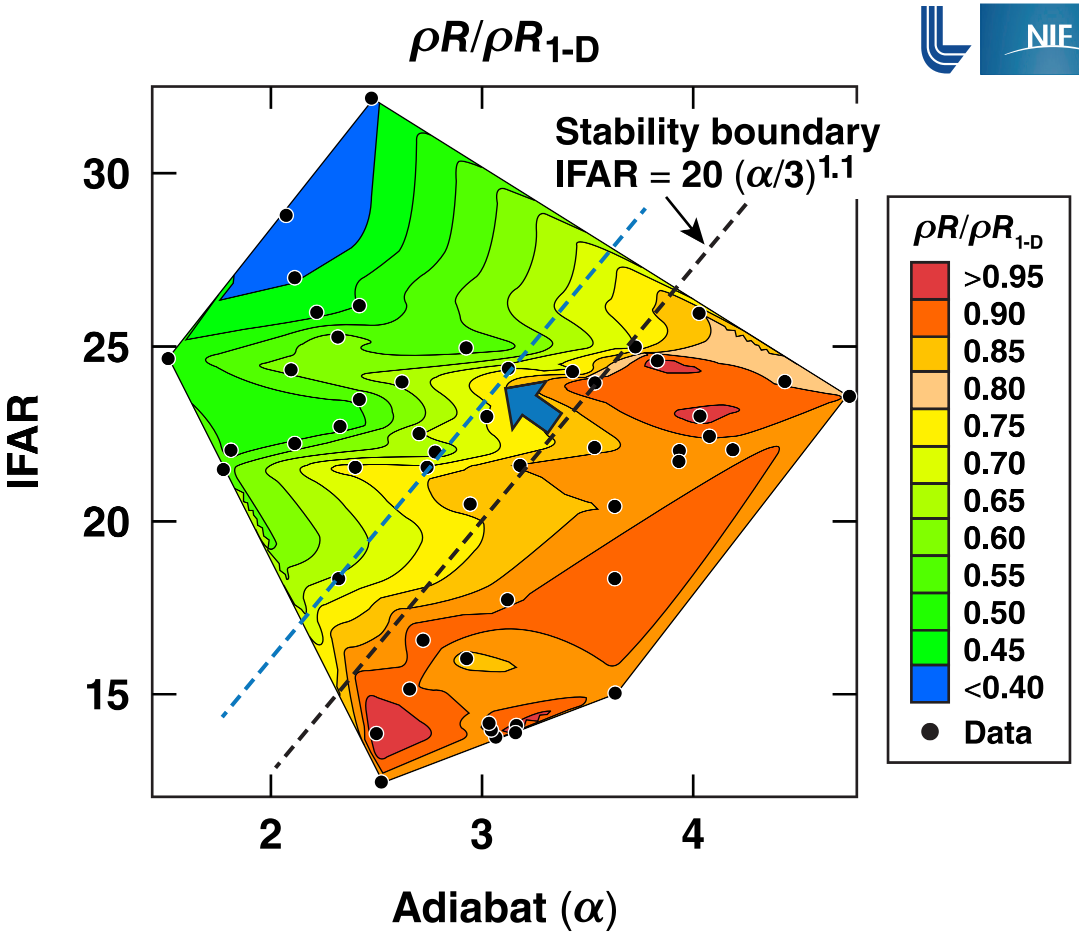
*V. N. Goncharov *et al.*, Phys. Plasmas 21, 056315 (2014).

**D. H. Froula *et al.*, Phys. Plasmas 20, 082704 (2013).

Irrespective of CBET losses, we can improve the central pressure by raising the stability threshold



$$\alpha = \frac{P}{P_F}$$

The pressure goal will require comparable $\alpha \sim 4$ performance at $\alpha \sim 3$.

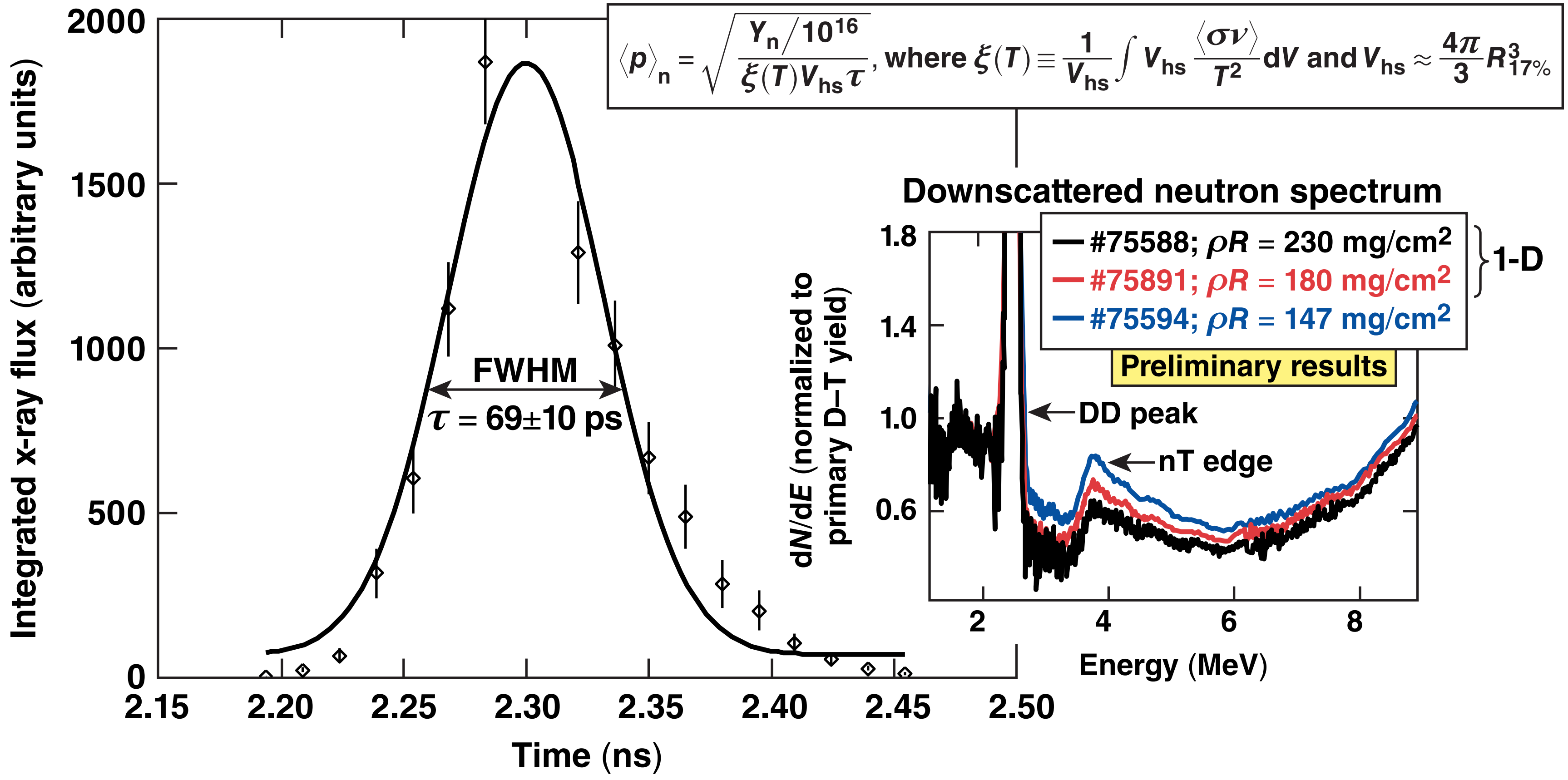
Efforts to raise the stability threshold will be mostly implemented by Q2FY15

- Reduce laser imprint using doped ablators and high-Z layers (routine warm)
- Improve drive uniformity with better power-balance algorithms (ongoing)
- Additional energy on target using dynamic bandwidth reduction (February)
- Reduce CBET and improve drive uniformity with a new set of phase plates (February)
- Install new instrumentation to improve the measurement accuracy

  of the central pressure and $P\tau$ (February)
- Eliminate target particulate sources to reduce ablation-surface Rayleigh–Taylor (RT) seeds (December–January)
- Purify the DT fuel supply and adjust the T:D ratio for maximum yield (50:50 in the gas phase) (completed)

Some of these capabilities have already improved layered implosion performance.

The x-ray burnwidth is being used to infer $\langle P \rangle_n$ and P_{peak}



$$\langle p \rangle_n = \sqrt{\frac{Y_n / 10^{16}}{\xi(T) V_{hs} \tau}}, \text{ where } \xi(T) \equiv \frac{1}{V_{hs}} \int_{V_{hs}} \frac{\langle \sigma v \rangle}{T^2} dV \text{ and } V_{hs} \approx \frac{4\pi}{3} R^3_{17\%}$$

The peak pressure, P_{peak}, can be inferred using profiles from *LILAC* (1-D).

C. Cerjan, P. T. Springer, and S. M. Sepke, Phys. Plasmas 20, 056319 (2013);
R. Betti *et al.*, Phys. Plasmas 17, 058102 (2010).

The most recent four-shock layered implosions are reasonably 1-D

UR LLE

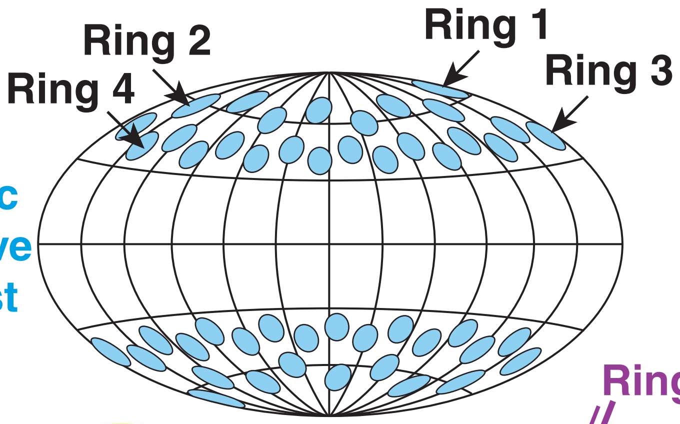
NIF NRL MIT Massachusetts Institute of Technology

	Shot	α/IFAR	YOC (1-D)	$\langle p \rangle_n$ (exp)/(1-D) (Gbar)	P_{peak} (exp)/(1-D) (Gbar)	X-ray burnwidth (exp)/(1-D) (ps)	T_i (exp/1-D) (keV)	Velocity (km/s)
Early 2013	69514	4.2/22	32%	29/73	41/100	88/62 (neutron)	4.0/3.5	380
Nov.	75588	4.0/20	43%	37/74	47/98	69/68	3.4/3.3	360
	75591	4.1/21	37%	32/57	40/76	78/74	3.2/3.2	360
				~50% 1-D	~50% 1-D	1-D	1-D	

The symmetric direct-drive ignition threshold for 1.8 MJ is $\langle P \rangle_n$ ~ 95 Gbar and P_{peak} ~ 120 Gbar.

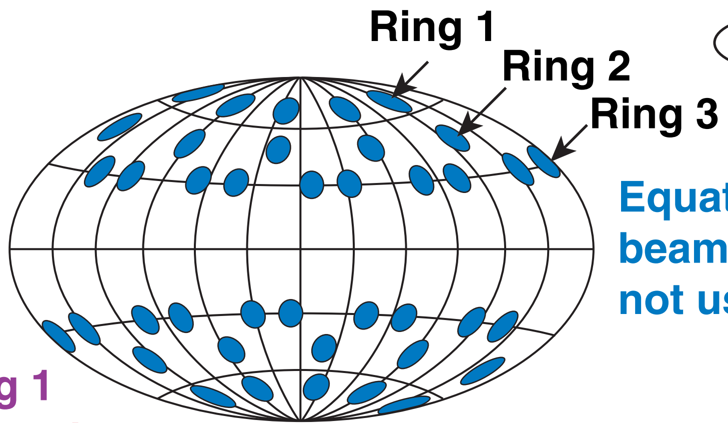
PDD* uses deterministic power imbalance to achieve nearly symmetric direct-drive on the NIF*

NIF PDD configuration

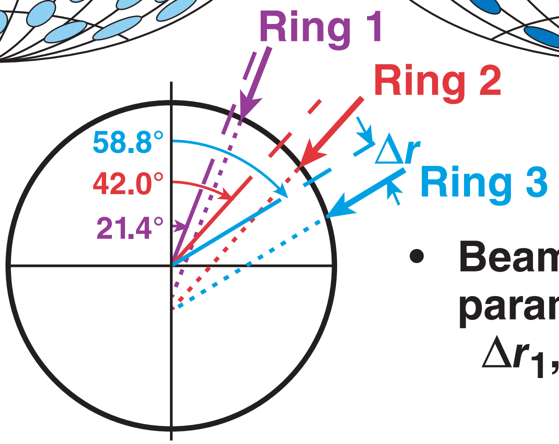


Symmetric direct-drive ports exist

OMEGA-symmetric PDD configuration



Equatorial beams are not used



- Beam shifts are parametrized by Δr_1, Δr_2, Δr_3,

The goal is to ignite a DT plasma in the PDD configuration and/or inform the decision to reconfigure for symmetric direct drive.

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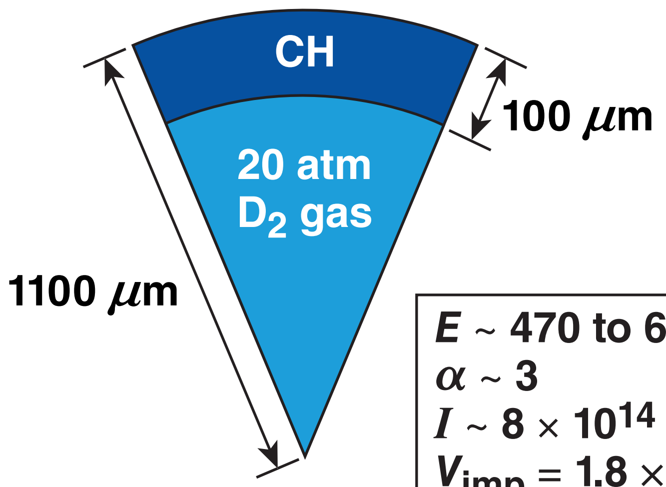
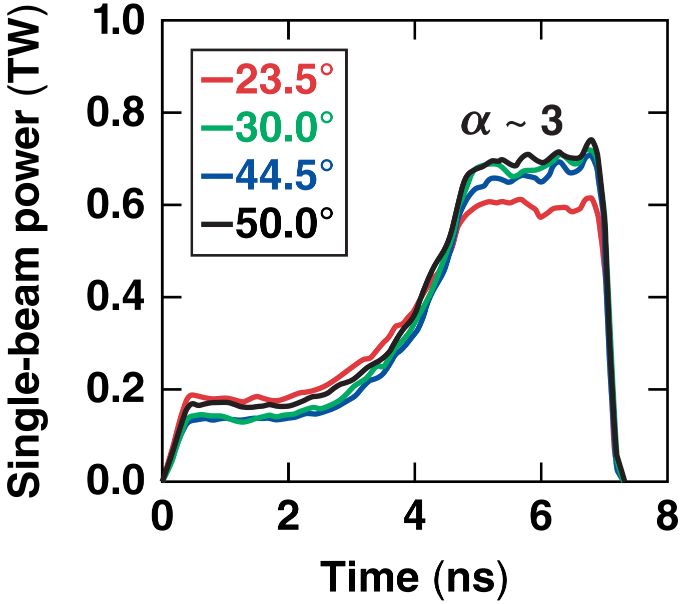
*R. S. Craxton *et al.*, Phys. Plasmas 12, 056304 (2005); F. J. Marshall *et al.*, J. Phys. IV France 133, 153 (2006).

The NIF PDD campaigns are designed to validate energetics and LPI predictions at ignition scale

14 shots since 2012

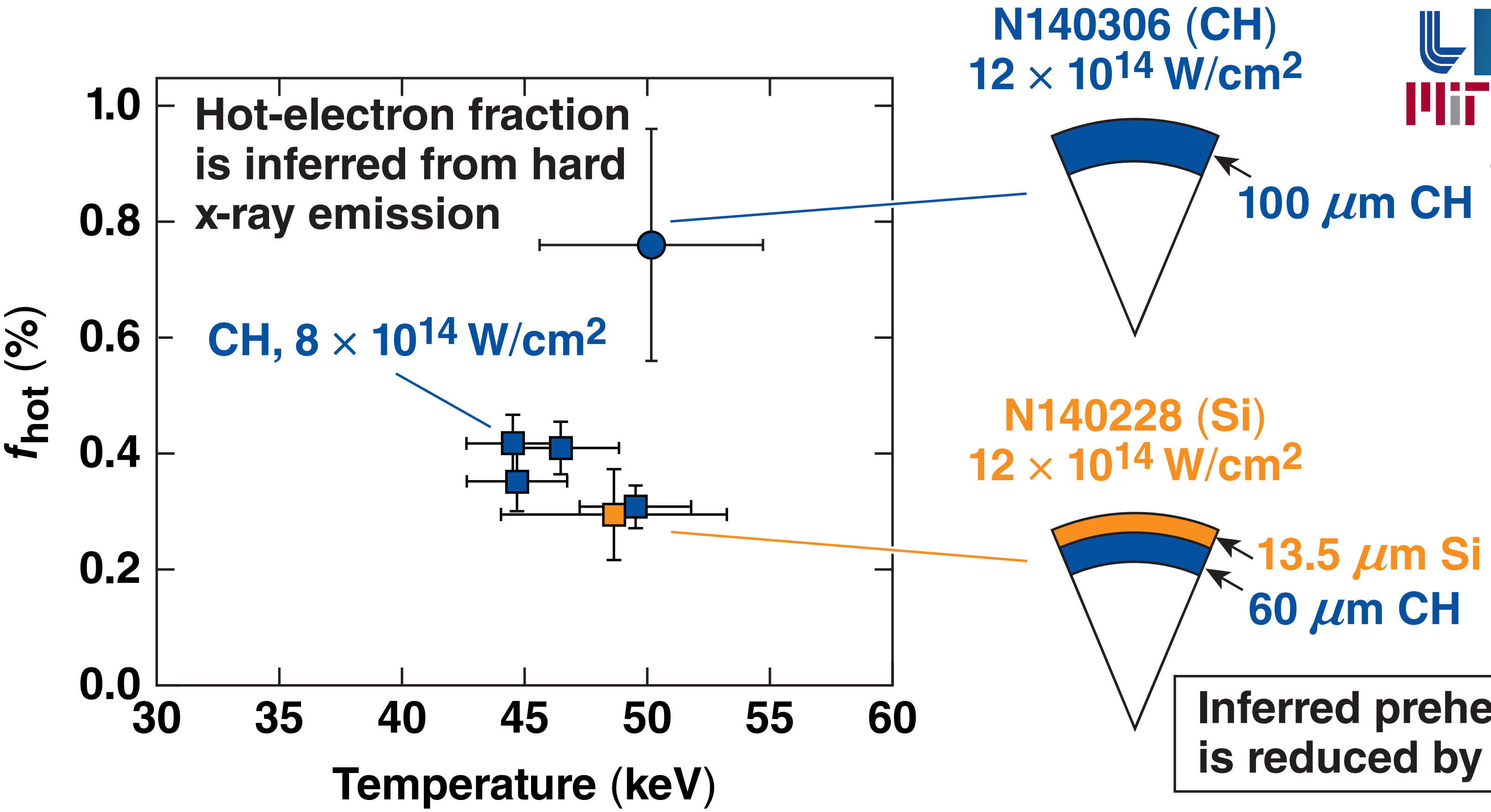


$E \sim$ 470 to 660 kJ
$\alpha \sim 3$
$I \sim 8 \times 10^{14}$ W/cm^2
$V_{imp} = 1.8 \times 10^7$ cm/s
IFAR$_{2/3}$ = 19



Dedicated PDD phase plates are being developed to mitigate nonuniformities and drive uncertainties associated with the indirect-drive (ID) configuration.

As demonstrated on OMEGA,* hot-electron preheat can be mitigated using mid-Z ablators for PDD implosions



Hot-electron fraction is inferred from hard x-ray emission

CH, 8 × 10^{14} W/cm^2

N140306 (CH)
12 × 10^{14} W/cm^2

100 μm CH

N140228 (Si)
12 × 10^{14} W/cm^2

13.5 μm Si

60 μm CH

Inferred preheat in Si is reduced by ~50%

A planar LPI experiment in FY15 will investigate the effect of beam angle of incidence on $2\omega_p$ hot-electron production.

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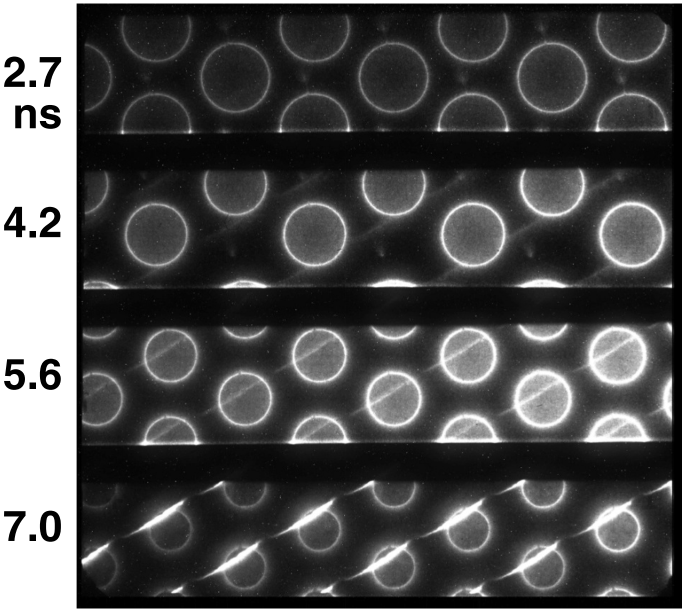
*J. F. Myatt *et al*., Phys. Plasmas 20, 052705 (2013);
D. H. Froula *et al*., Plasma Phys. Control. Fusion 54, 124016 (2012).

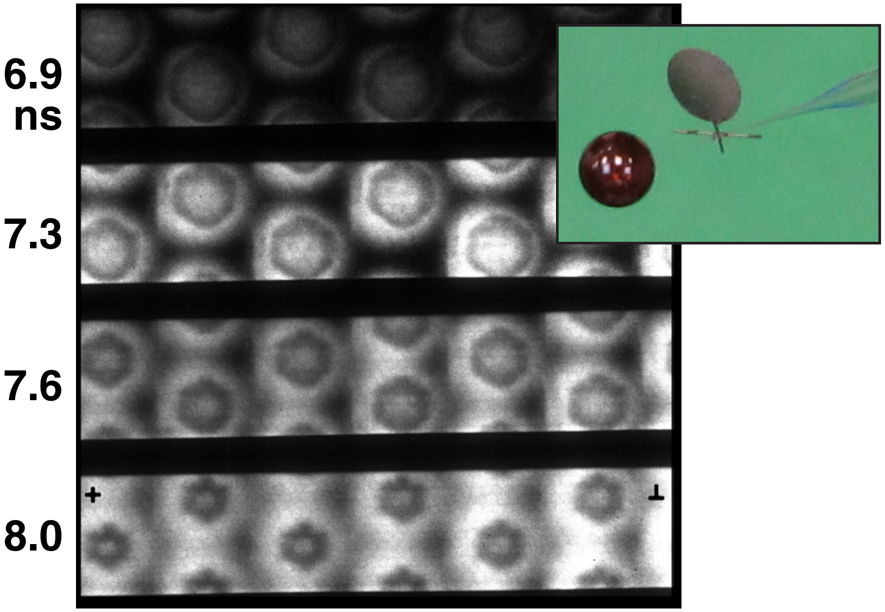
Self-emission* and radiography are used to infer the shell motion in PDD implosions on the NIF



Ablation surface imaging

N140612-001

(0,0) – self-emission



Inner shell surface imaging

N140612-001

(90,78) – Fe BL

In-flight shell imaging (used to infer the velocity) is an effective integrated measure of the laser coupling.

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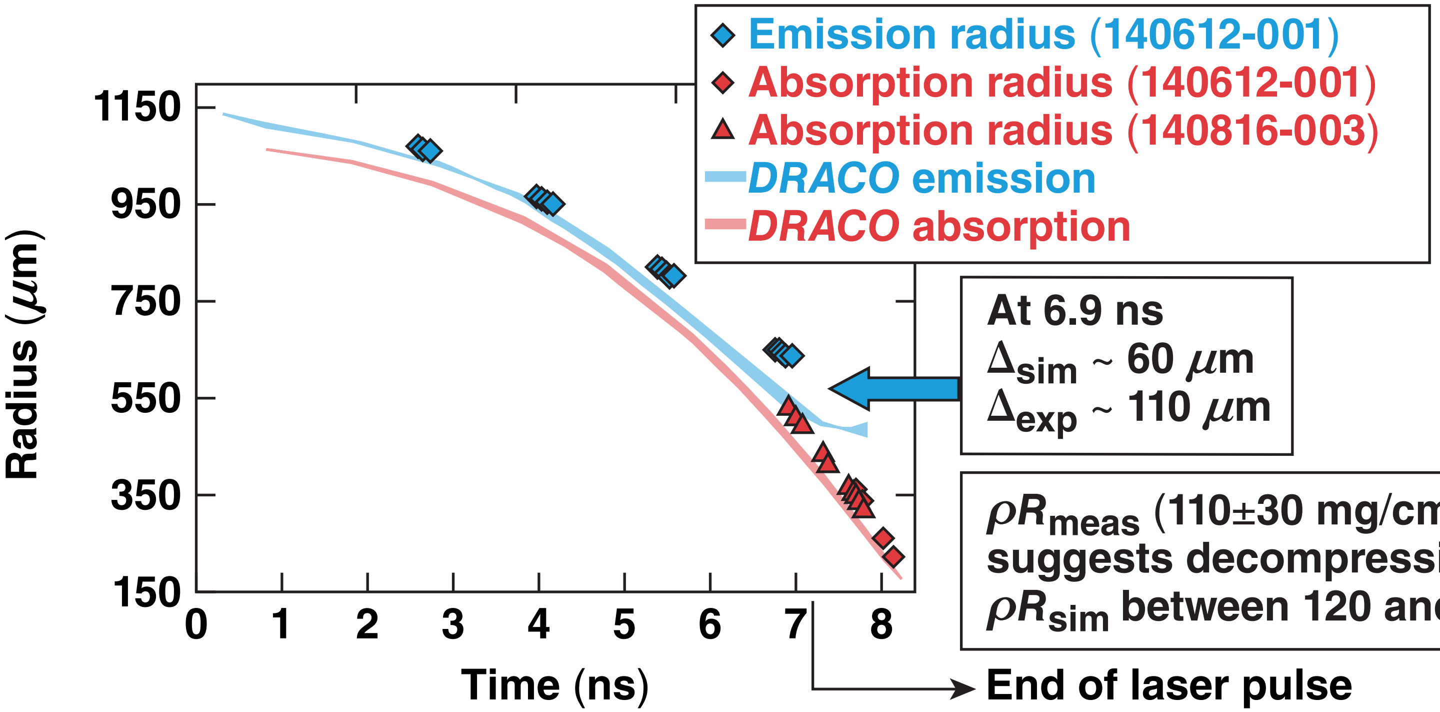
*D. T. Michel *et al*., Rev. Sci. Instrum. 83, 10E530 (2012).

Delayed trajectories relative to 2-D simulations suggest decompression at the ablation surface*



At 6.9 ns
Δ_{sim} ~ 60 μm
Δ_{exp} ~ 110 μm

ρR_{meas} (110±30 mg/cm^2) also suggests decompression with ρR_{sim} between 120 and 280 mg/cm^2

End of laser pulse

Target-surface quality, preheat, and imprint are the likely culprits and will be investigated with experiments in 2015.

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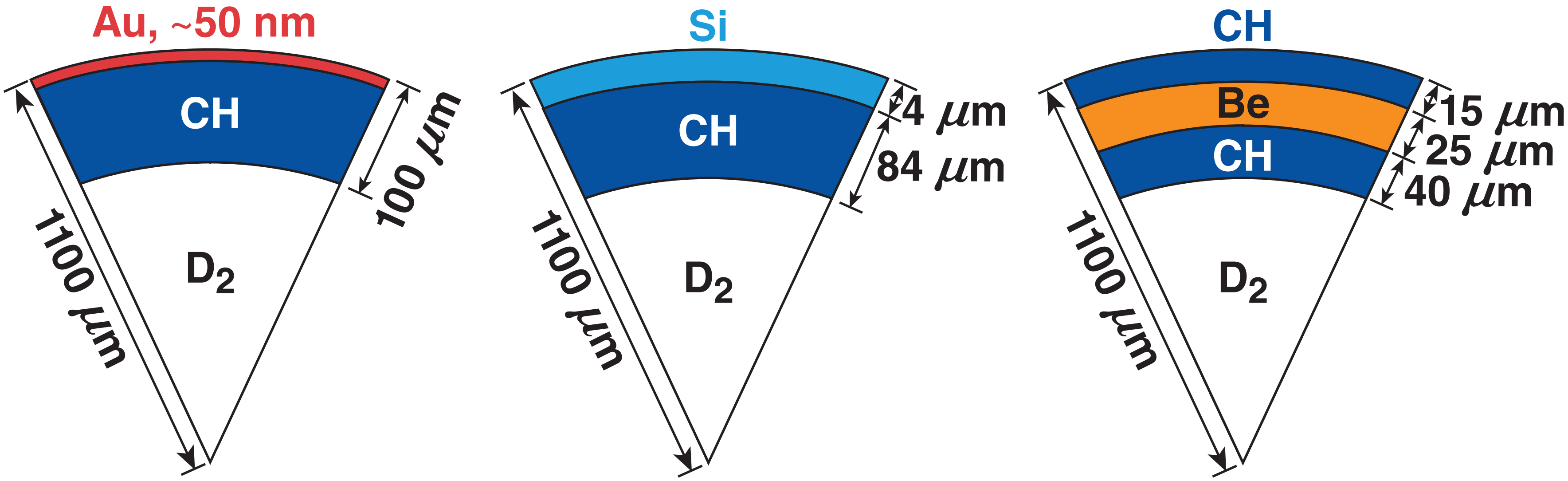
*M. Hohenberger *et al.*, "Polar-Direct-Drive Experiments on the National Ignition Facility," submitted to Phys. Plasmas (invited).

FY15–Implosion Platforms

Spherical implosions will continue to be an important PDD platform in FY15



Polished shell with thin Au overcoat for reduced hydro-instability seeds

The mass ablation rate can be measured using compoind ablators*

Be provides superior hydroefficiency**

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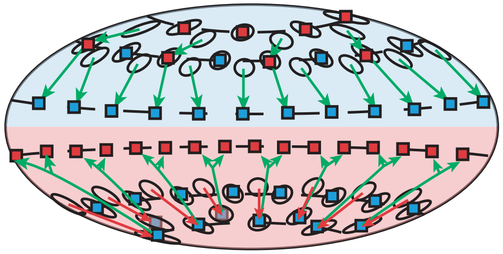
*D. T. Michel to be submitted to Phys. Rev. Lett.

**D. T. Michel *et al.*, Phys. Rev. Lett. 111, 245005 (2013).

The PDD campaign on the NIF requires staging a number of new capabilities over the next several years

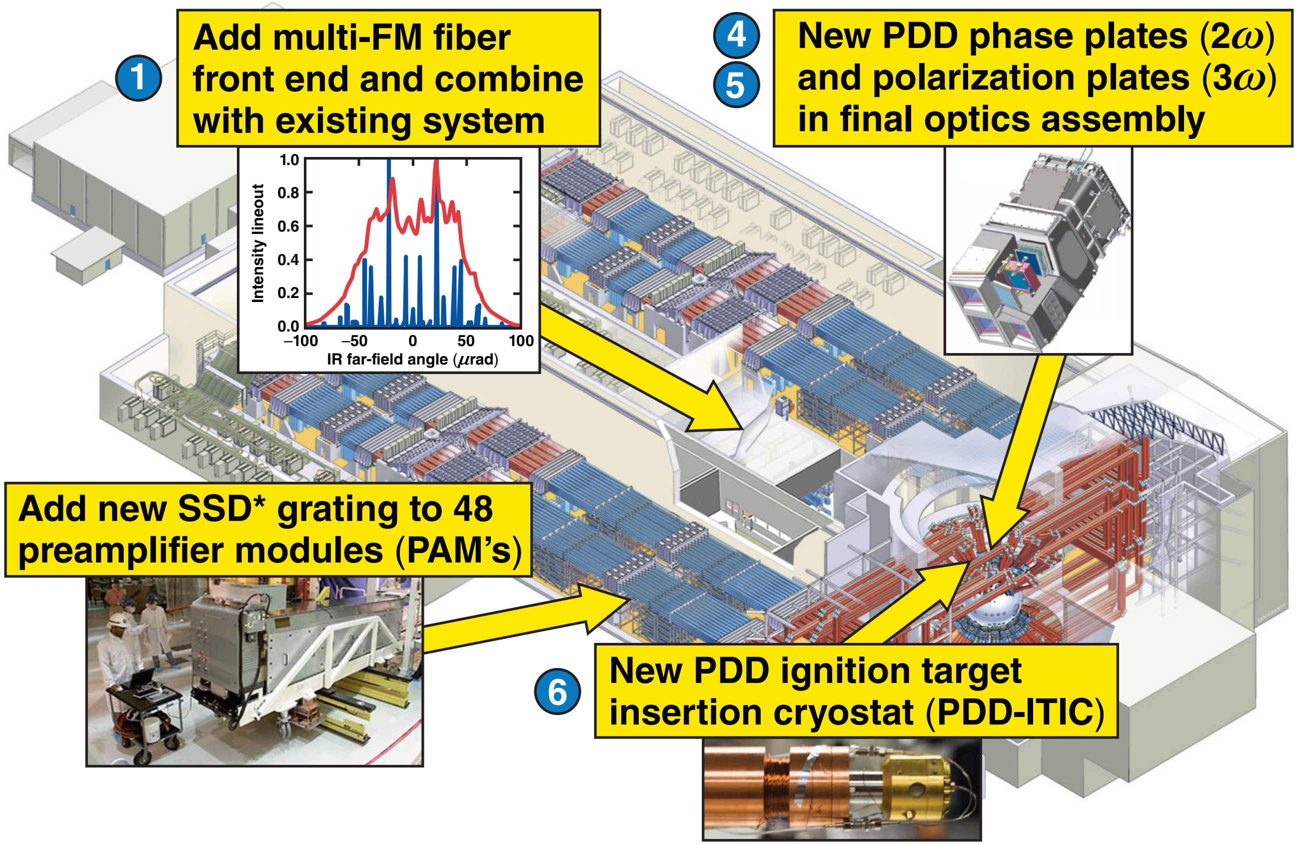
Hemispheric wavelength detuning

②



$\Delta\lambda \geq -6$ Å (UV)
$\Delta\lambda \geq +6$ Å (UV)

Currently capability:
$\Delta\lambda \sim \pm 2$ Å (UV)



① Add multi-FM fiber front end and combine with existing system

④ ⑤ New PDD phase plates (2ω) and polarization plates (3ω) in final optics assembly

③ Add new SSD* grating to 48 preamplifier modules (PAM's)

⑥ New PDD ignition target insertion cryostat (PDD-ITIC)

The Laser Path-Forward Working group is developing the implementation plans for these new capabilities.

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*SSD = smoothing by spectral dispersion

Summary/Conclusions

Our near-term path forward is to achieve pressures in excess of 50 Gbar on OMEGA

- Near 1-D implosions are being performed at an $\alpha \sim 4$ with $V_{\text{imp}} \sim 370$ km/s and inferred $\langle P \rangle_{\text{n}} \sim 37$ Gbar and $P_{\text{peak}} \sim 47$ Gbar
- New capabilities are expected to push pressures above 50 Gbar in FY15 and much closer to hydro equivalence in FY16/17
- The first 14 polar-direct-drive (PDD) shots on the National Ignition Facility (NIF) confirm predicted coupling and preheat mitigation
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Our long-time goal is to do layered PDD implosions on the NIF.

Shape

The self-emission inferred shape evolution matches the radiography data very well