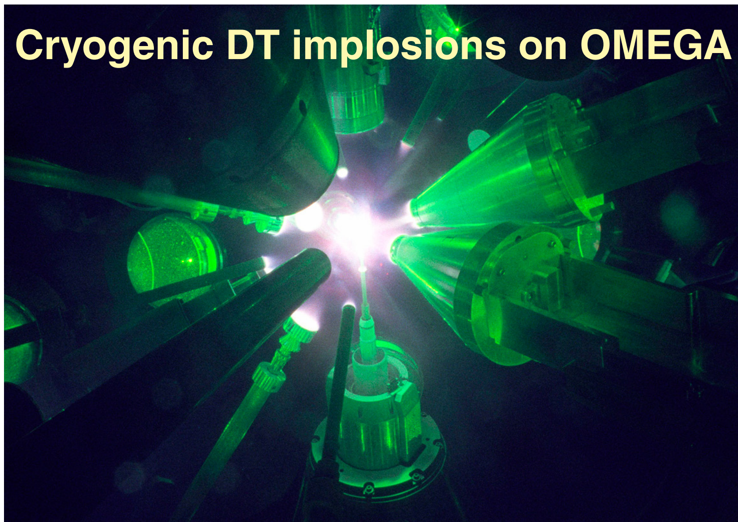
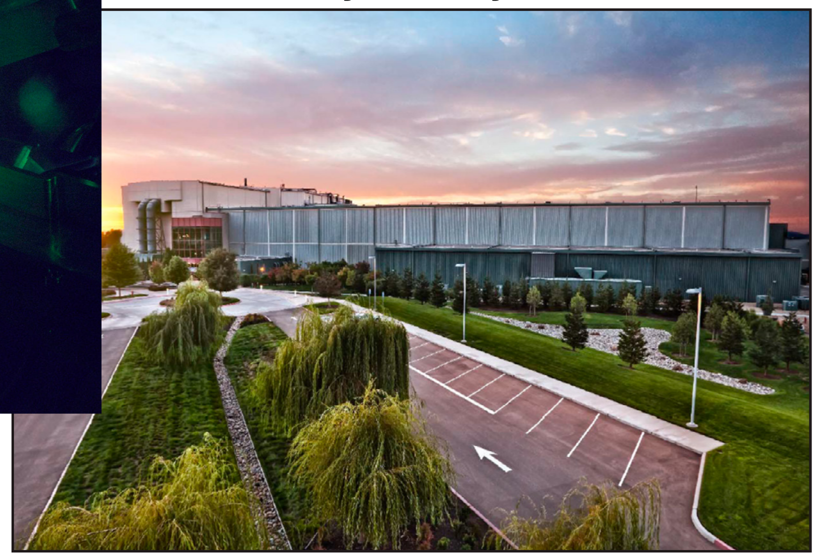
Progress and Plans for Polar-Direct-Drive Inertial Confinement Fusion from OMEGA to the National Ignition Facility



… and LPI/symmetry on the NIF



NIF Town Hall
56th Annual Meeting of the American Physical Society Division of Plasma Physics
New Orleans, LA
27–31 October 2014

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

Summary

Direct laser illumination (direct drive) is an alternate approach for creating a burning DT plasma with MJ-class lasers

- Polar direct drive (PDD) is a multi-laboratory collaboration
- Symmetric direct-drive cryogenic DT implosions on OMEGA provide the scientific basis for a direct–drive ignition campaign
- PDD experiments on the National Ignition Facility (NIF) are validating drive symmetry and laser–plasma instability (LPI) modeling at the appropriate energy/plasma scale
- The "PDD Laser Path-Forward" working group is developing the plan to integrate new laser capabilities and dedicated optics for improved PDD implosion performance

The PDD campaign has grown from 4 shots in FY13 to a planned 15 shots in FY15.

Collaborators

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

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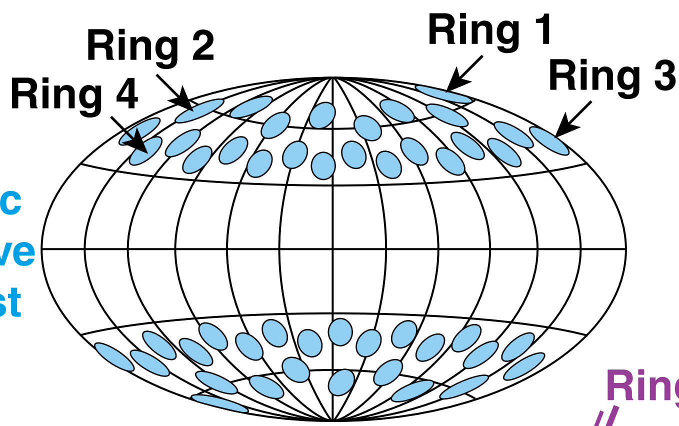
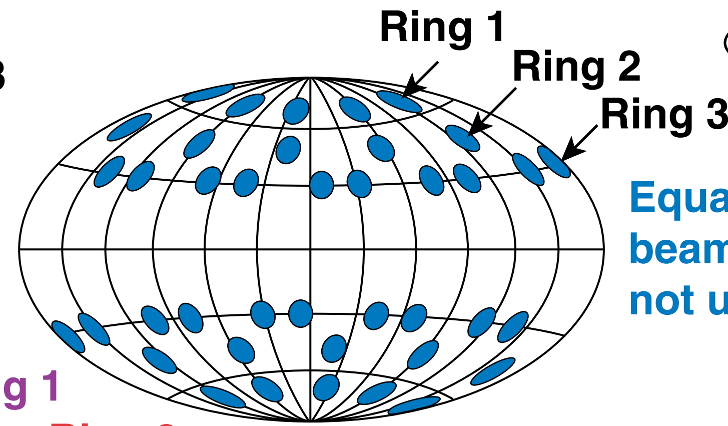
NIF PDD configuration

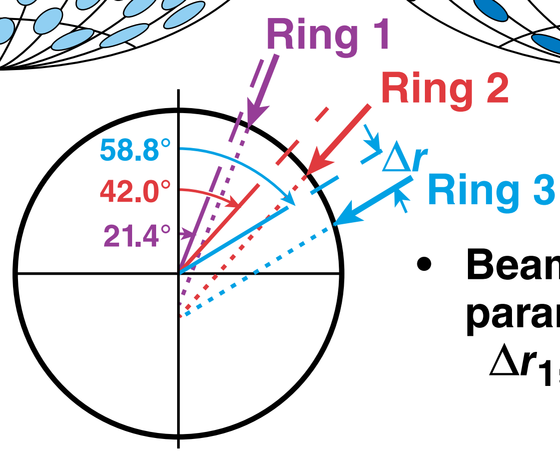


Symmetric direct-drive ports exist

OMEGA-symmetric PDD configuration



Equatorial beams are not used



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

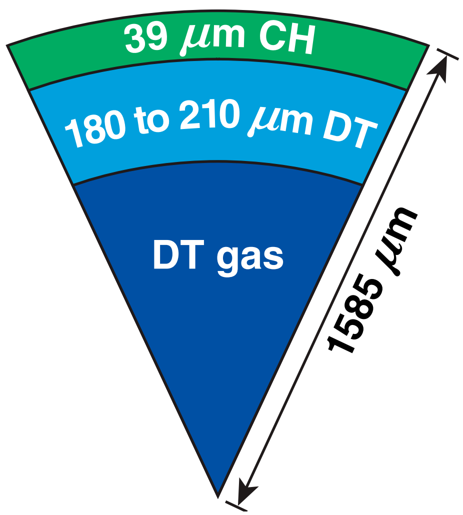
The goal is to ignite a DT plasma in the PDD configuration or inform the decision to reconfigure for symmetric direct drive.

TC7194o

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

Symmetric direct drive is a compelling alternative for laser-driven ICF

Basic point design of symmetric 1.8-MJ ignition design*



Relative to indirect drive (ID):

- At least 7× more fuel to the same V_{imp}
- 4× lower stagnation pressure required (~100 Gbar for margin 1 symmetric, 1.8 MJ)
- 1.5× lower convergence
- 3× higher fuel adiabat
- Margin comparable to ID ($P\tau/P\tau_{ign}$)

More adaptable to innovative and high-risk approaches (shock and fast ignition, magnetization) with superior diagnostic access.

*V. N. Goncharov *et al.*, Phys. Rev. Lett. 104, 165001 (2010).

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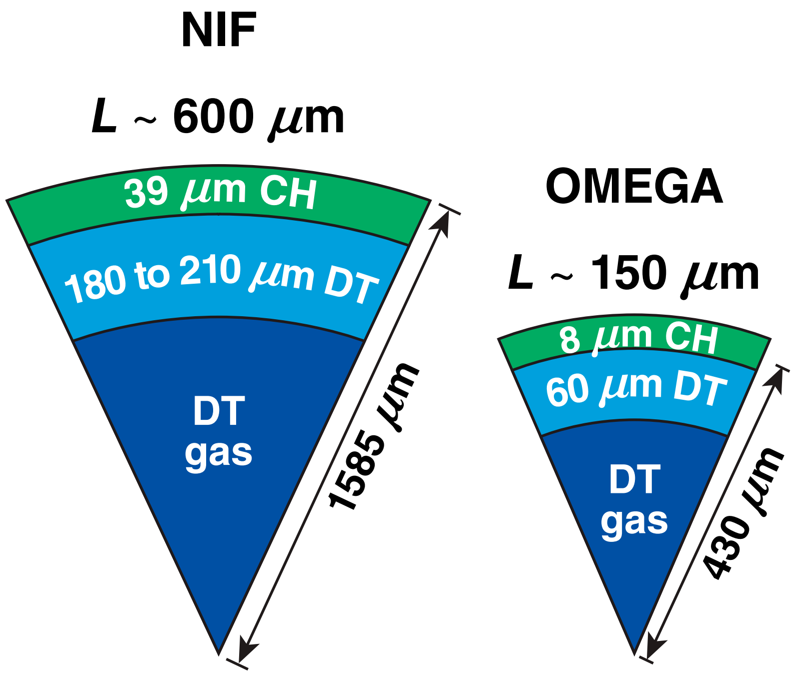
Solutions for the scientific and technical challenges require experimental campaigns on both OMEGA and the NIF

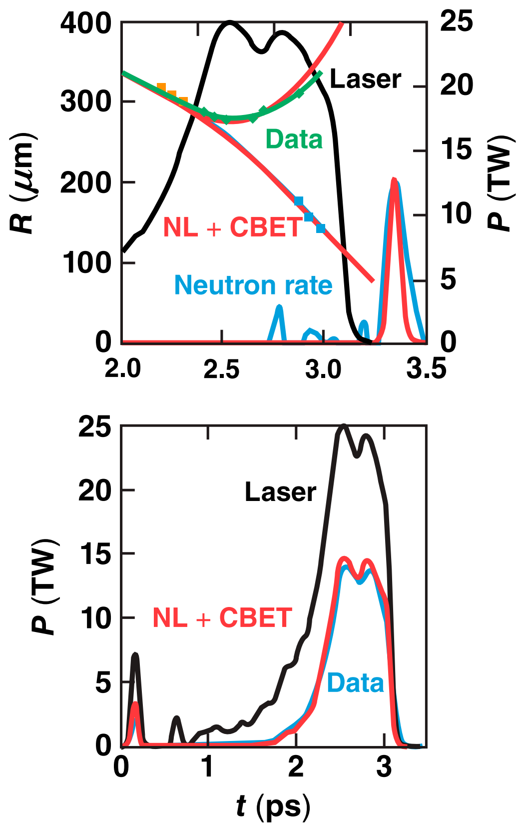


- Drive uniformity
- Laser imprint
- Energy coupling & thermal transport
- Preheat (hot electron)
- Cross-beam energy transfer (CBET)
- Velocity > 350 km/s

Improve modeling and prediction with hundreds of shots/year on OMEGA and verify prediction at ignition scale with tens of shots/year on the NIF.

*V. N. Goncharov *et al.*, Phys. Rev. Lett. 104, 165001 (2010).

The physics models used for PDD target design are being developed and tested with layered DT implosions 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 IFAR†
- Campaign underway to improve $P\tau$ by mid-2015

The goal for LLE/OMEGA is to demonstrate ignition hydro-equivalent implosion performance by the end of the decade.

*D. T. Michel *et al*., JO4.00009, this conference.
**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*., NO4.00013, this conference.
‡V. N. Goncharov *et al*., Phys. Plasmas 21, 056315 (2014).

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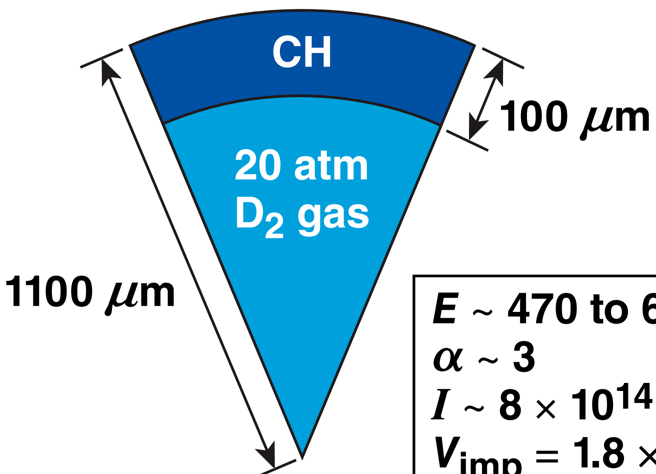
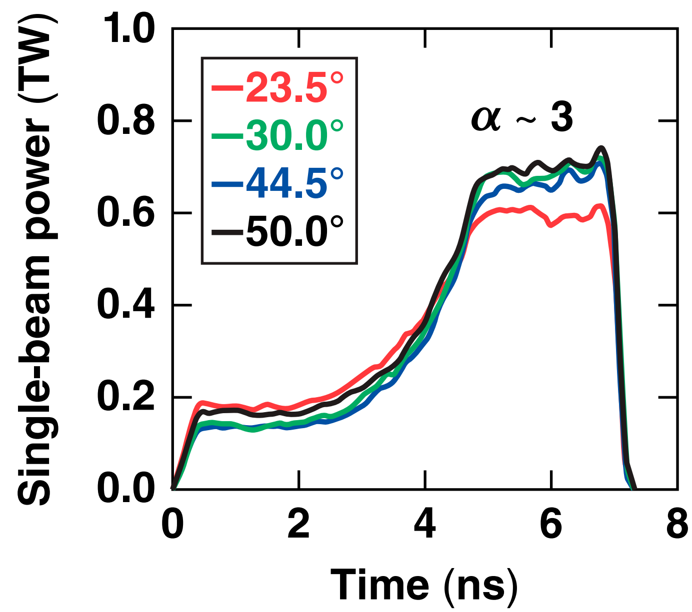
The NIF PDD campaigns* are designed to validate energetics and laser–plasma instability predictions at ignition scale



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



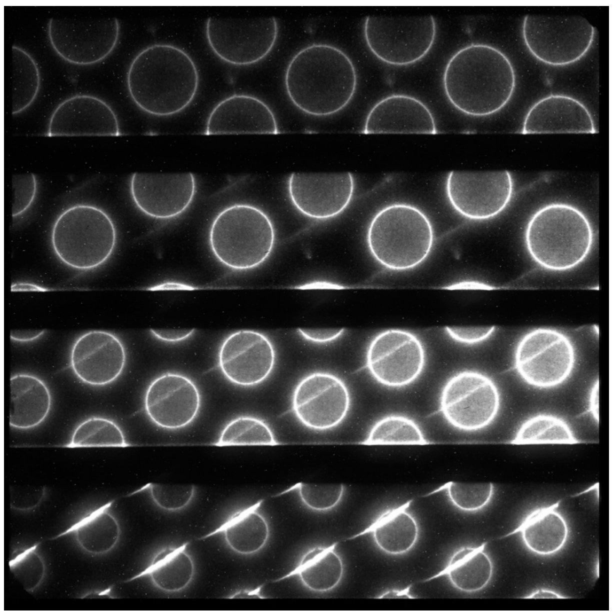
Dedicated PDD phase plates are being developed to mitigate nonuniformities and drive uncertainties associated with the ID configuration.

*P. B. Radha *et al*., Phys. Plasmas 20, 056306 (2013);
M. Hohenberger, CI1.00001, this conference.

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

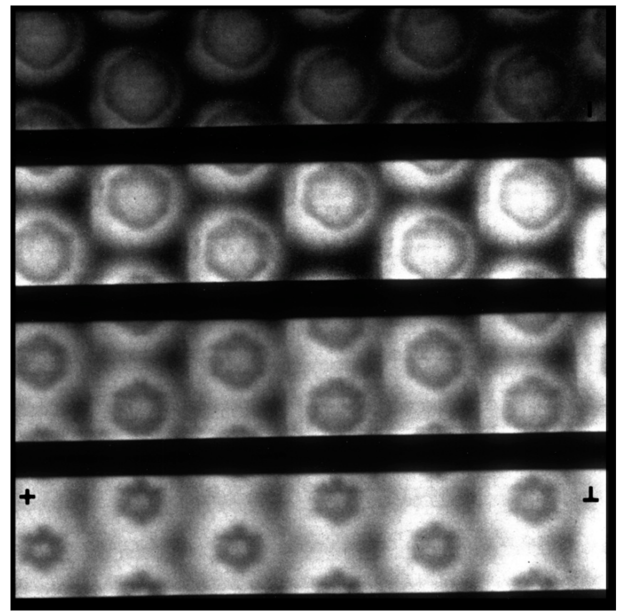
Ablation surface imaging
N140612-001
(0,0) – self-emission

2.7 ns
4.2
5.6
7.0



Inner shell surface imaging
N140612-001
(90,78) – Fe BL

6.9 ns
7.3
7.6
8.0



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

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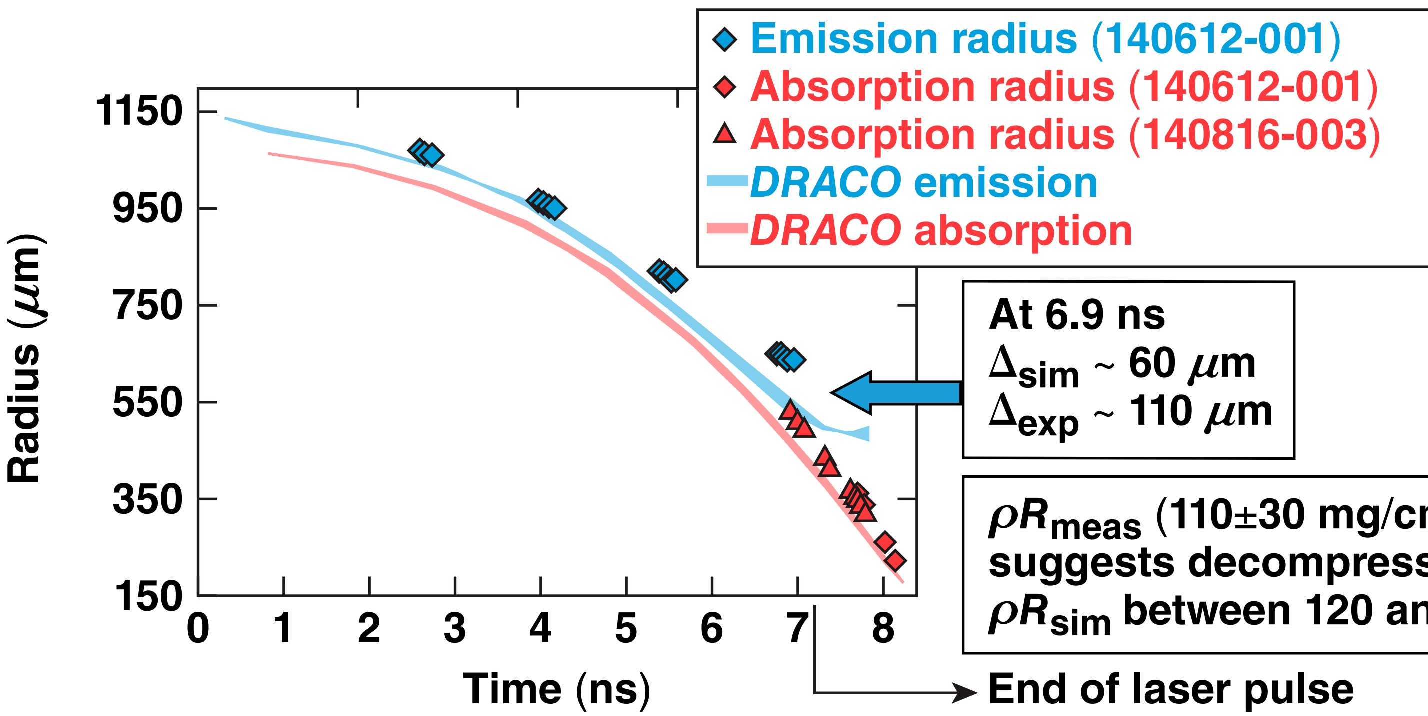
*D. T. Michel *et al.*, Rev. Sci. Instrum. 83, 10E530 (2012).

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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*P. B. Radha *et al.*, JO4.00013, this conference.

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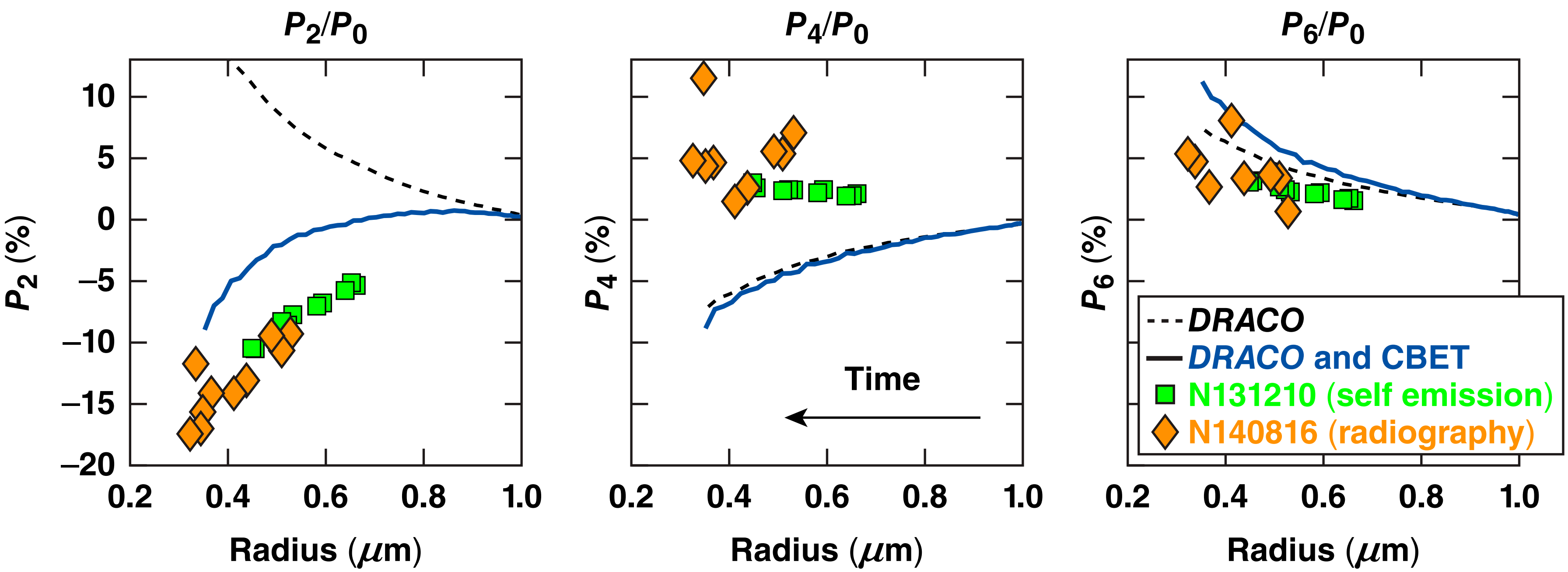
Two-dimensional shape predictions qualitatively agree with the measured evolution when CBET losses are included*



The shell symmetry can be predictably changed using beam pointing and defocus as well as pulse shaping.

*M. Hohenberger, CI1.00001, this conference.

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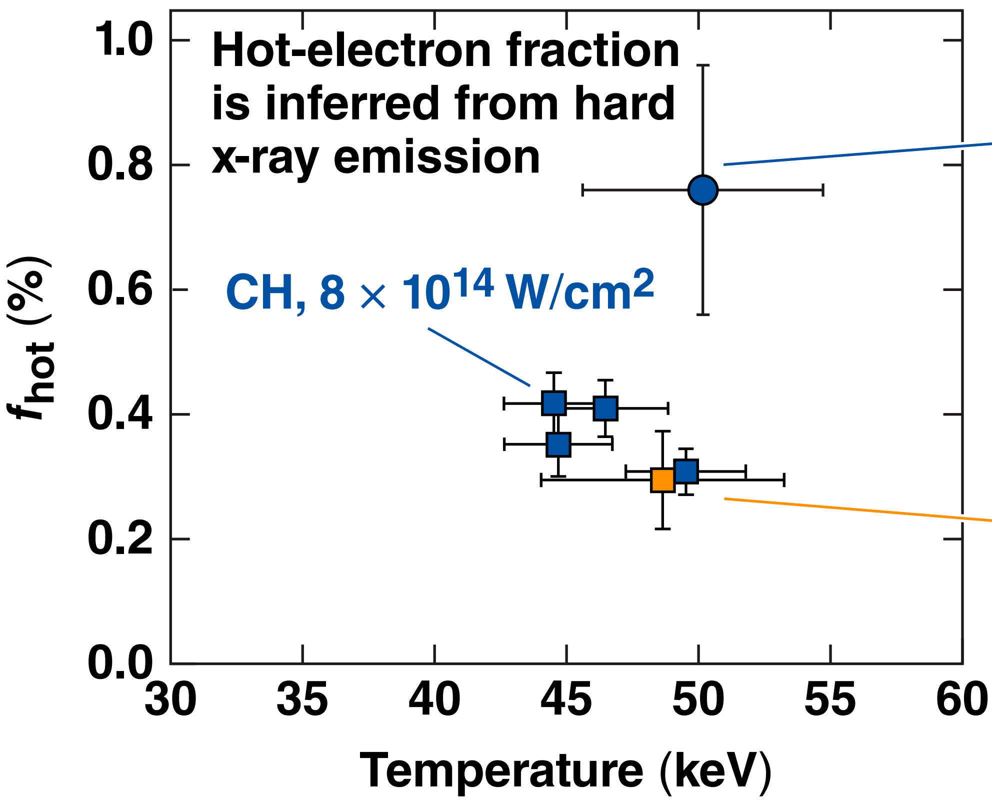
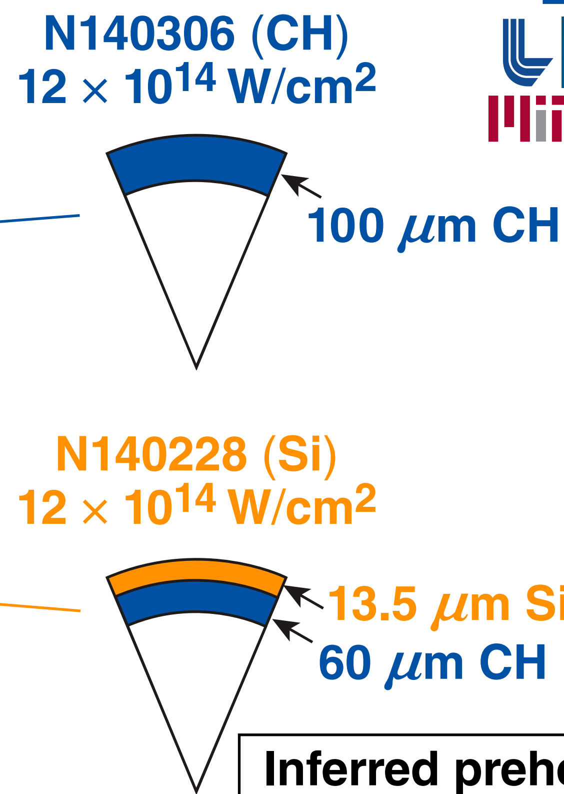
As demonstrated on OMEGA,* hot-electron preheat can be mitigated using mid-Z ablators for PDD implosions





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.

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

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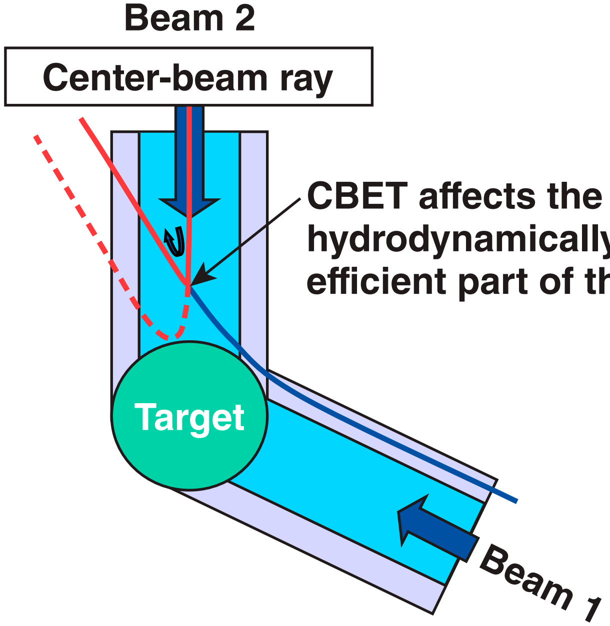
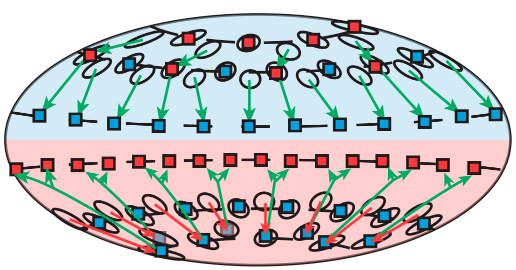
CBET reduces the ablation pressure late in time by up to 50%*





NIF hemispheric wavelength detuning

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

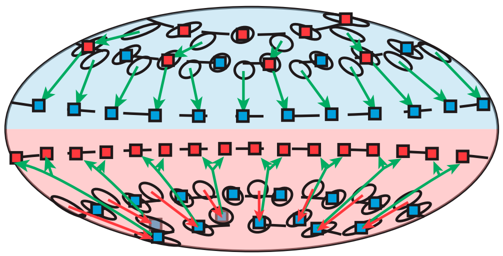
- Minimize the light going over the "horizon" of the capsule (best for OMEGA)
  - laser spots underfill the target
  - "zooming" changes the laser spot size during the pulse**
- Detune the laser frequencies to minimize the simulated Brillouin scattering (SBS) resonance volume in which CBET occurs (best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

*V. N. Goncharov *et al*., Phys. Plasmas 21, 056315 (2014).
**D. H. Froula *et al*., NO4.00013, this conference.

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

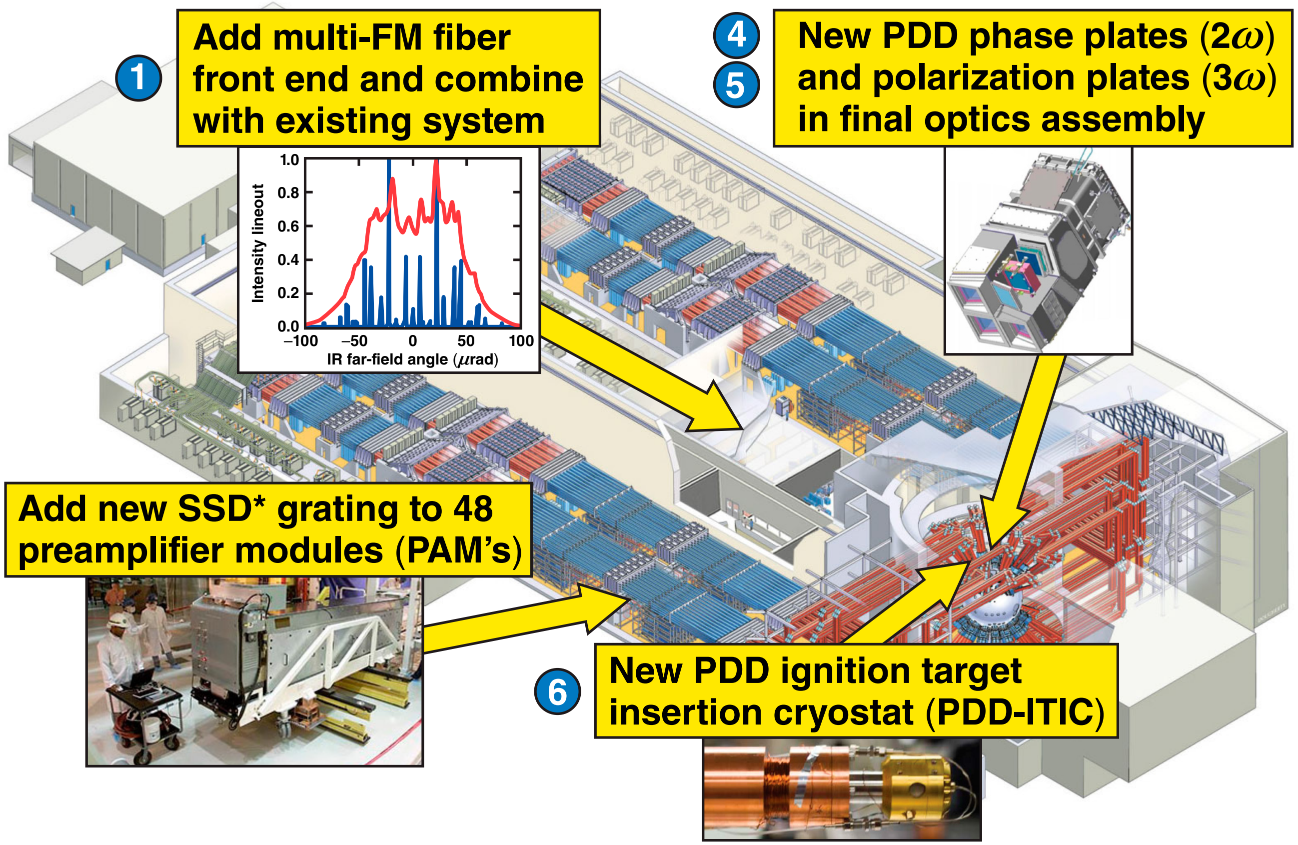
Hemispheric wavelength detuning

2



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

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



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

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*SSD = smoothing by spectral dispersion

Near-term PDD experiments on the NIF follow from the results of the first 12 shots and recent campaigns on OMEGA

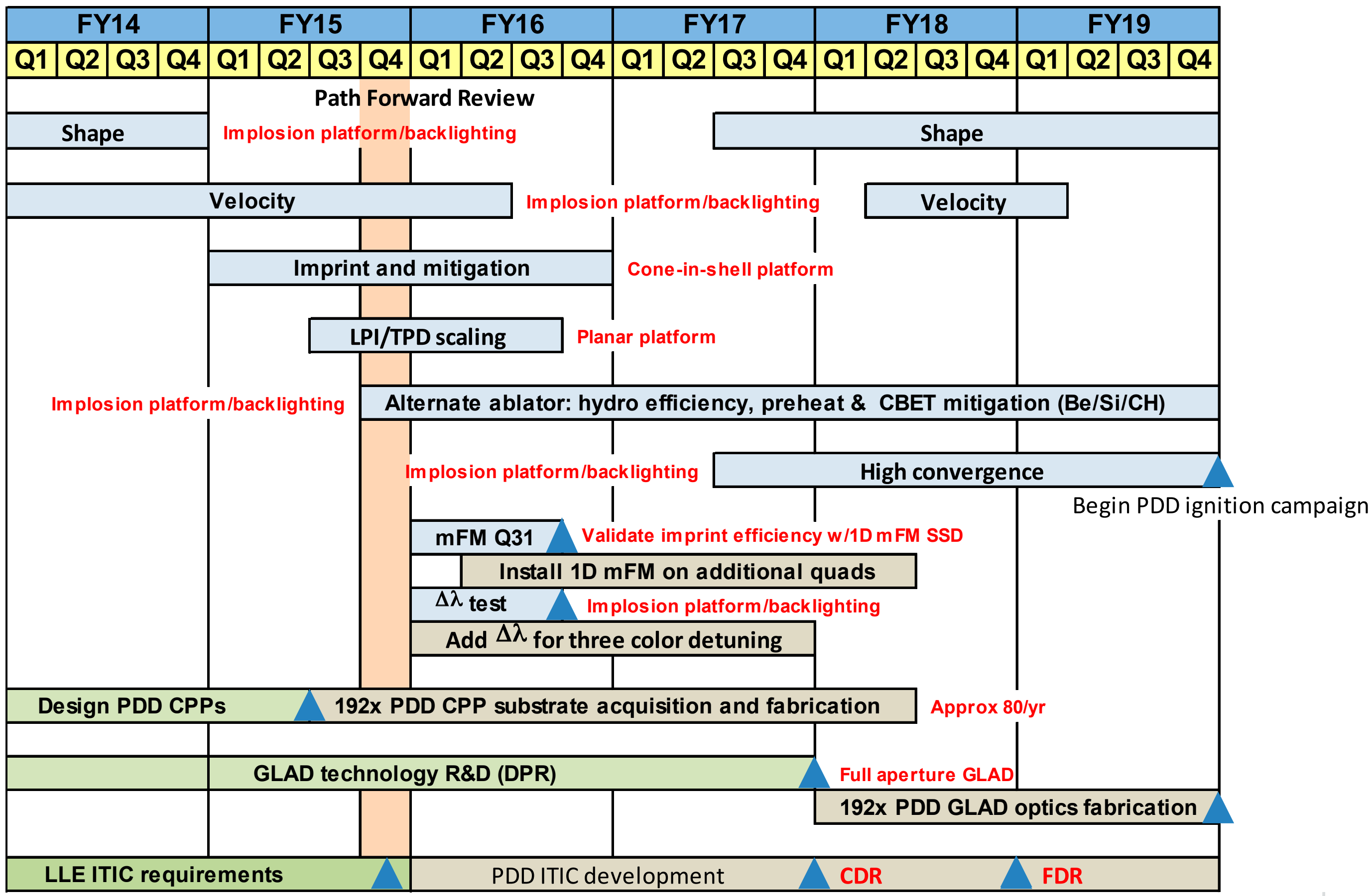
	Q1	Q2	Q3	Q4
Imprint/Rayleigh–Taylor growth (cone-in-shell)*	3 (Nov)	2 (Mar)		
Reduced nonuniformity seeds (spherical with overcoat)**		2 (Jan)		2 (Aug)
LPI/two-plasmon decay (TPD) scaling (planar)			2 (Apr)	
Mass ablation rate (spherical Si ablator)***				2 (Aug)
Alternate ablator (Be)†				2 (Sept)

- Validation of single-quad multi-FM SSD smoothing and hemispheric $\Delta\lambda$ to mitigate CBET have been deferred to FY16

*G. Fiksel *et al.*, Phys. Plasmas 19, 062704 (2012).
**S. P. Obenschain *et al.*, Phys. Plasmas 9, 2234 (2002).
***A. K. Davis *et al.*, JO4.00014, this conference.
†D. T. Michel *et al.*, Phys. Rev. Lett. 111, 245005 (2013).

The PDD experimental plan follows the implementation schedule of the required laser capabilities

This is not yet a resource loaded plan



Direct laser illumination (direct drive) is an alternate approach for creating a burning DT plasma with MJ-class lasers

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NIF NRL MIT Massachusetts Institute of Technology

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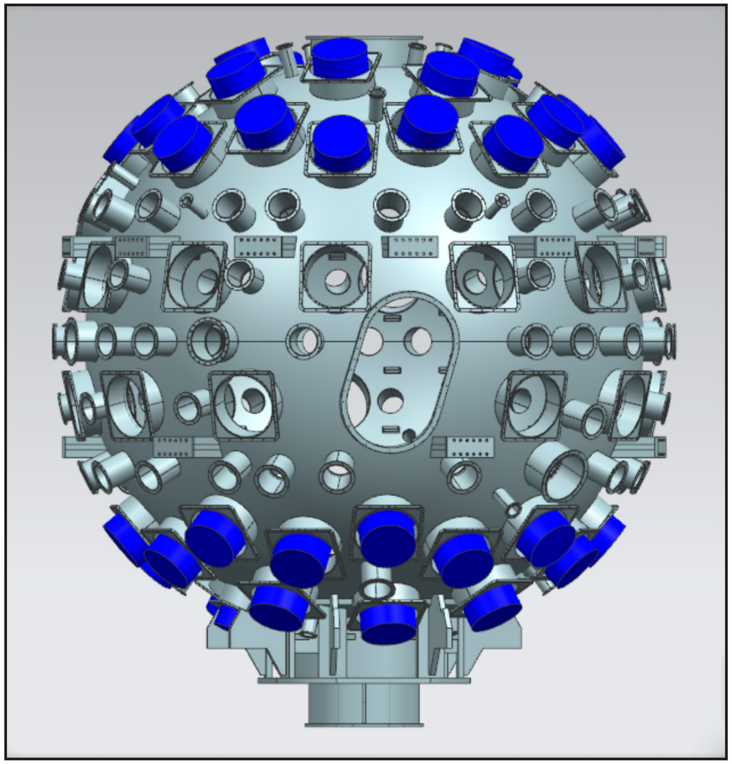
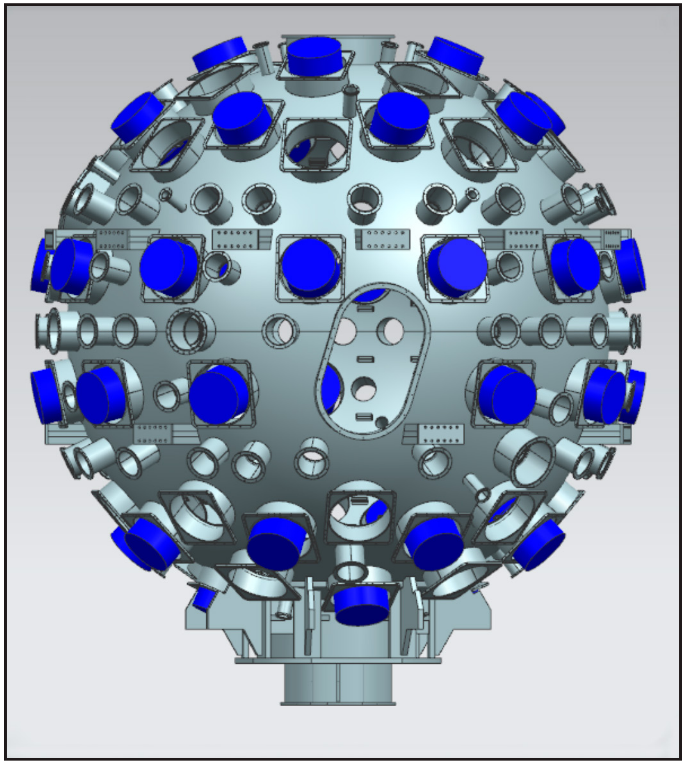
The commitment of the NIF to improve operational efficiencies and expand capabilities underpins the continued success of the PDD campaign.

The NIF target chamber was designed to support symmetric direct drive

X-ray drive (beams around the poles)



Symmetric drive



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