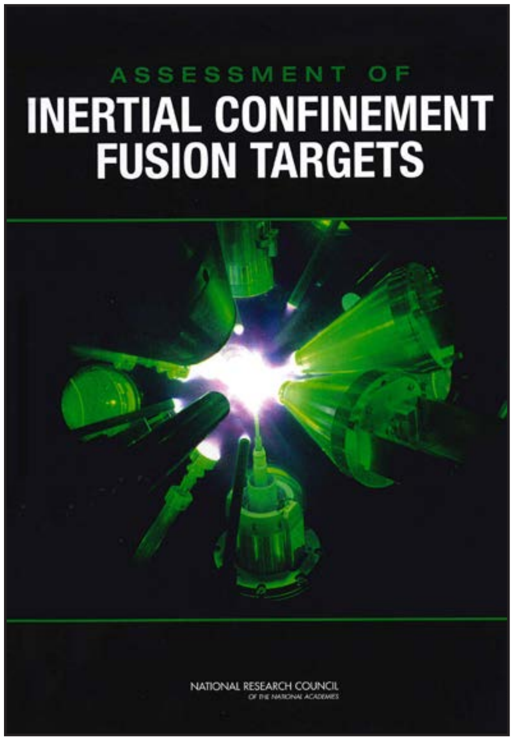
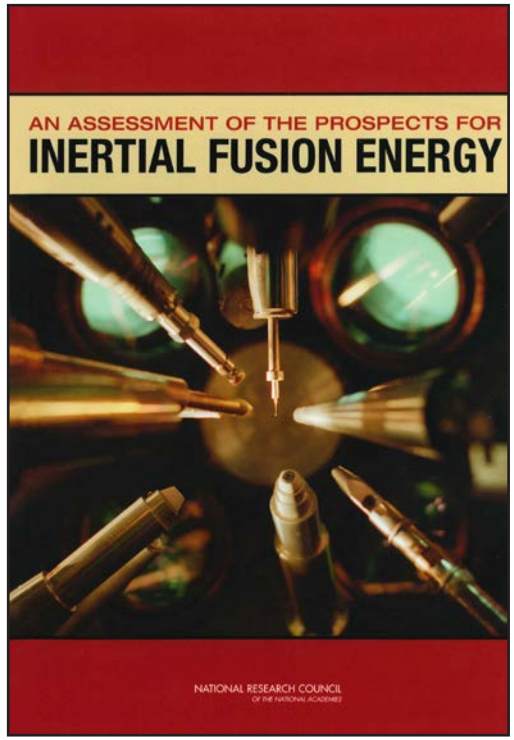
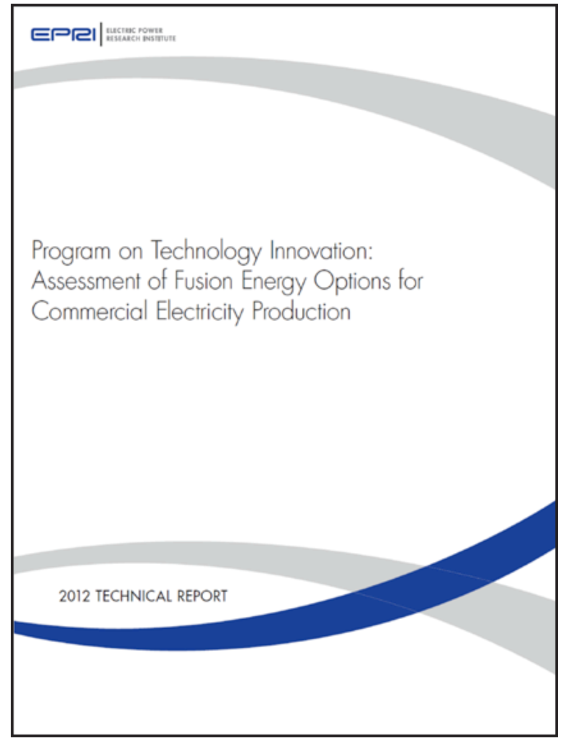
Perspectives on Inertial Fusion Energy







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Summary

The development of commercial inertial fusion energy (IFE) will be a long process

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- There are a number of steps along the path
  - demonstrate ignition on the National Ignition Facility (NIF)—nothing happens without this!
  - develop a robust and reliable ignition platform
  - develop the technologies—drivers and materials
  - build an intermediate facility that integrates most of the technologies
    - perhaps symmetric direct drive
  - prove IFE will be cost effective compared to other commercial sources
- Direct drive has advantages for laser-driven IFE
  - more energy coupled to the fuel than indirect drive
    - more massive targets mean higher gain
  - simplest possible targets

The direct-drive–ignition concept could be validated with polar drive on the NIF.

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Direct drive allows for higher coupling efficiency so that significantly more fuel can be compressed to ignition conditions than with indirect drive (ID)

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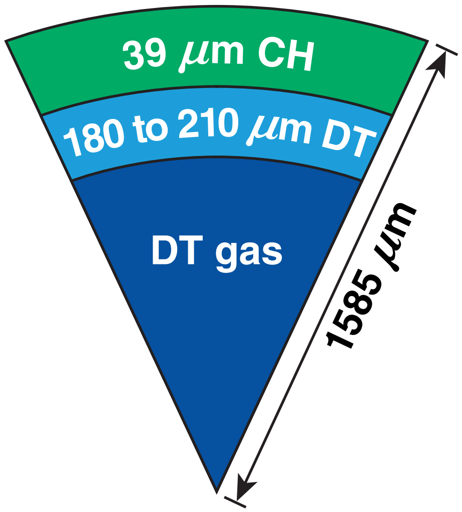
Basic point design of symmetric 1.8-MJ ignition design*



Apart from design details

- 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 ($P\tau/P\tau_{ign}$)
- Relatively simple plasma conditions compared to a hohlraum
- Simple, low-cost targets with little debris
- Open geometry for diagnostic access

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

The National Academy of Science's IFE study highlighted the potential of direct drive

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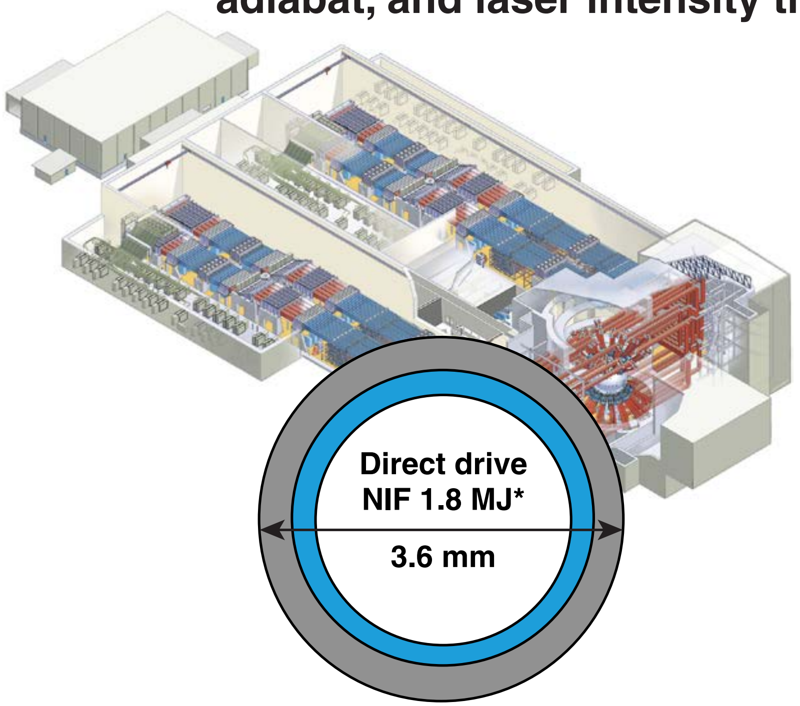
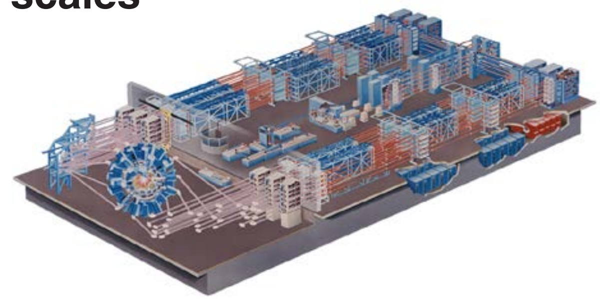
- "The leader in direct drive inertial confinement fusion with solid-state lasers is the Laboratory for Laser Energetics (LLE) at the University of Rochester, which operates the Omega Laser Facility (OMEGA and OMEGA EP) for the National Nuclear Security Administration (NNSA)."
- Key recommendations/conclusions from the NAS study[1] are
  - *Recommendation 2-1: The target physics programs on NIF, Nike, Omega, and Z should receive continued high priority. The program on NIF should be expanded to include direct drive and alternate modes of ignition*
  - *Recommendation 4-7: The achievement of ignition with laser indirect drive at the National Ignition Facility should not preclude experiments to test the feasibility of laser direct drive*
  - *Conclusion 4-6: The prospects for ignition using laser direct drive have improved enough that it is now a plausible alternative to laser indirect drive for achieving ignition and for generating energy*

[1] *An Assessment of the Prospects for Inertial Fusion Energy* (The National Academies Press, Washington, DC, 2013).

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

- **Hydrodynamic similarity is ensured by keeping the implosion velocity, adiabat, and laser intensity the same at the two scales****



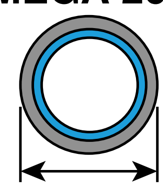


Scale 1:70 in energy

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

OMEGA 26 kJ



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

*V. N. Goncharov *et al*., Phys. Rev. Lett. 104, 165001 (2010).
**R. Betti, "Theory of Ignition and Hydro-Equivalence for Inertial Confinement Fusion," presented at the 24th IAEA Fusion Energy Conference, San Diego, CA, 8–13 October 2012.

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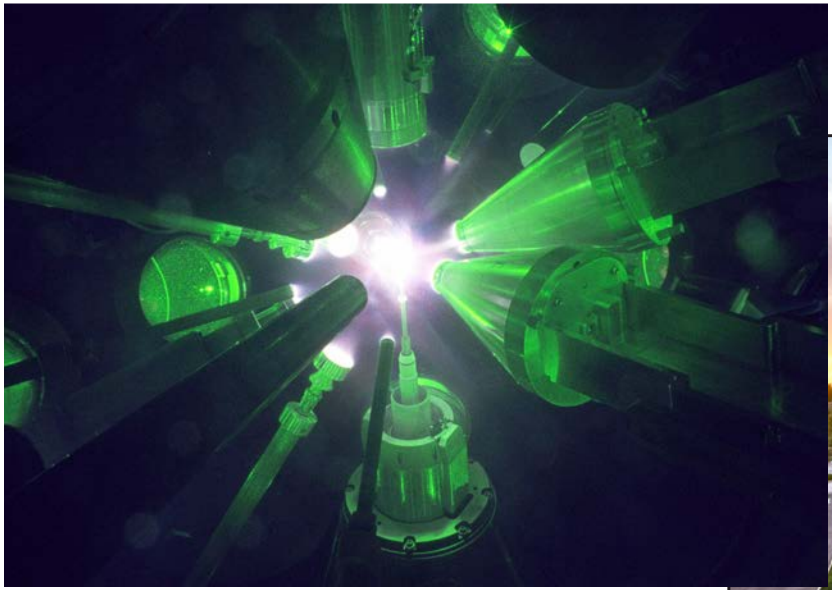
LLE's strategy is to demonstrate ignition hydro-equivalent implosion performance on OMEGA while validating laser–plasma instability (LPI) modeling and symmetry control at ignition scale on the NIF

Cryogenic DT implosions on OMEGA



... and LPI/symmetry on the NIF

Repointing the beams toward the equator is critical to achieve nearly symmetric drive in the NIF geometry (polar drive)

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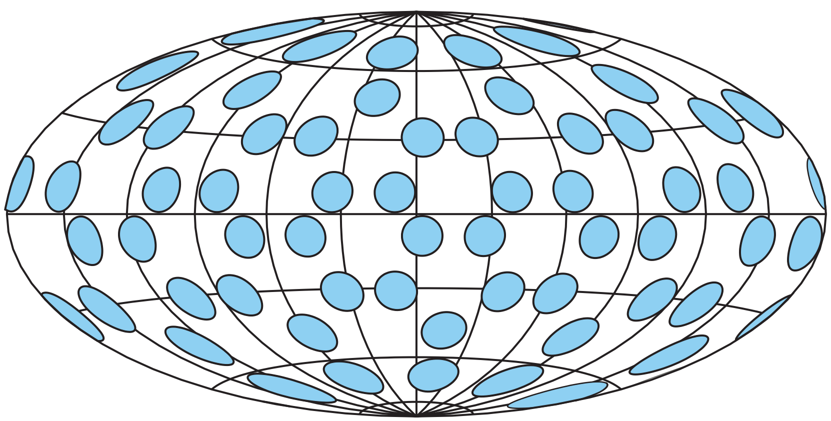
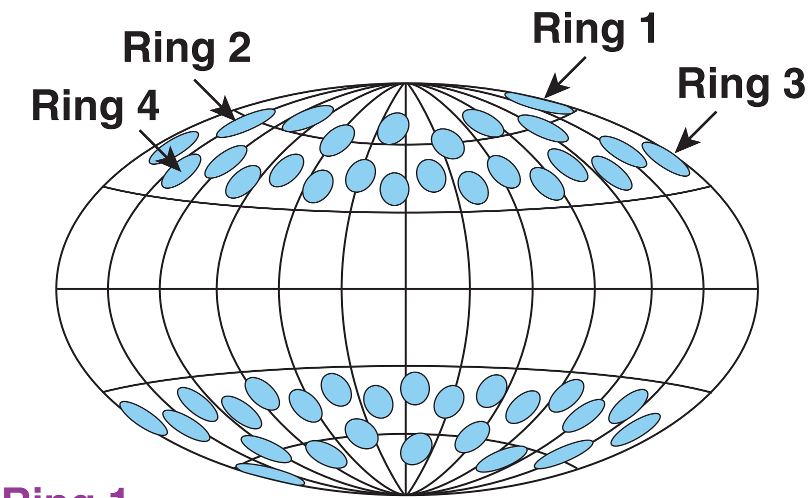
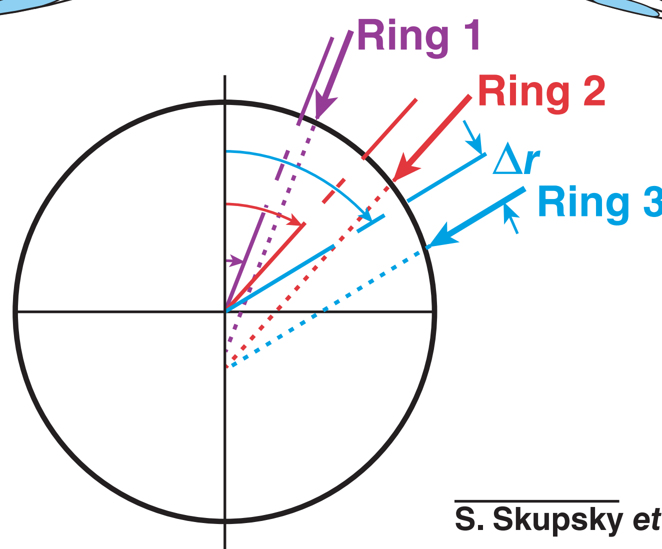
OMEGA illumination



NIF configuration

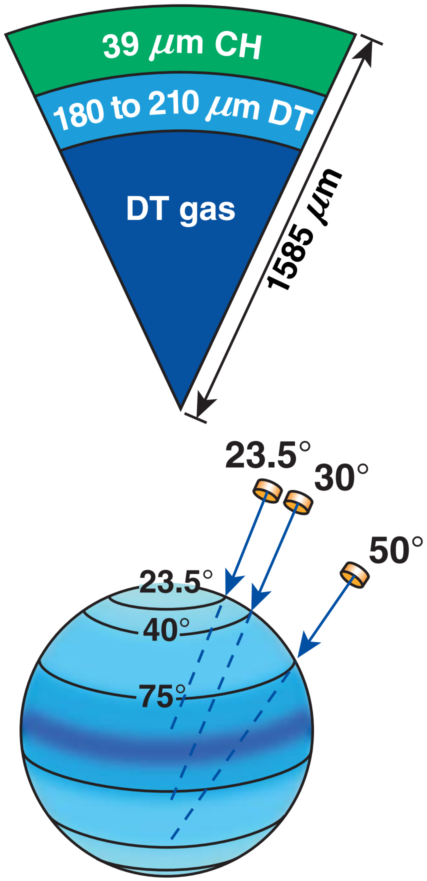


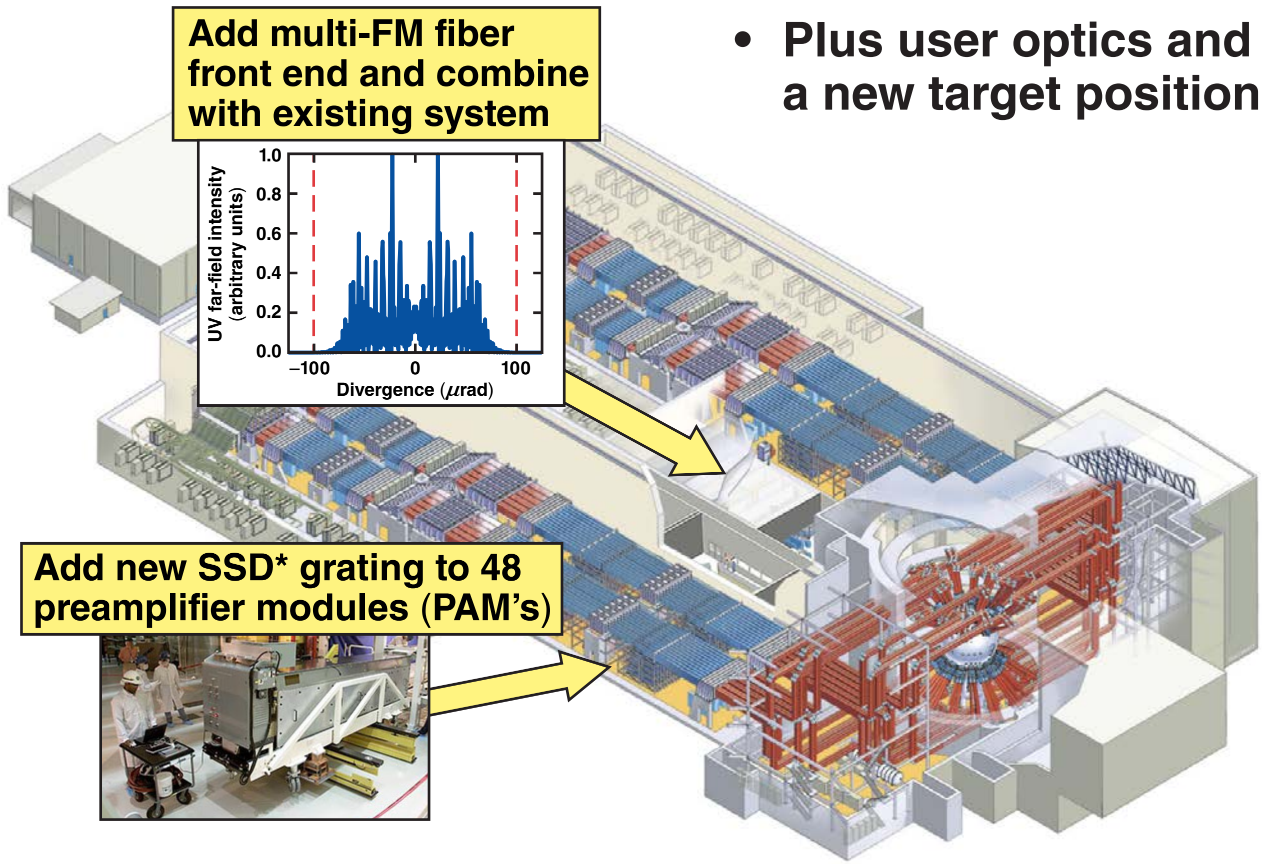


- **Beam shifts are parametrized by Δr**

S. Skupsky *et al.*, Phys. Plasmas 11, 2763 (2004).

Performing a polar-drive (PD)–ignition campaign on the NIF does not require a major facility modification





- Plus user optics and a new target positioner

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*Smoothing by spectral dispersion

The Polar Drive Working Group has identified the key near-term deliverables on the path to ignition

- Experimentally demonstrate the predicted single-beam smoothing using 1-D multi-FM SSD (FY13 Path Forward milestone)
- Experimentally establish symmetry control and test/validate laser–plasma interaction (LPI) modeling at near-ignition scale using the ID configuration
  - we will need to do better hydro experiments to fully test the LPI and further improve symmetry
- Complete the modeling required to validate design energetics and symmetry requirements for ignition-scale PD experiments
  - currently at the verification stage
- Increase the central pressure in OMEGA implosions to 50 to 60 Gbar
  - this will require some cross-beam energy transfer (CBET) mitigation
- Validate the baseline scheme for polarization rotation: glancing-angle deposition (GLAD) optics
- Develop detailed implementation plans for
  - dedicated PD optics
  - 1-D multi-FM SSD
  - the ignition target insertion cryostat (ITIC)

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