The National Ignition Facility and the Ignition Campaign

Presentation to

AAAS 2013 Annual Meeting

February 14-18, 2013

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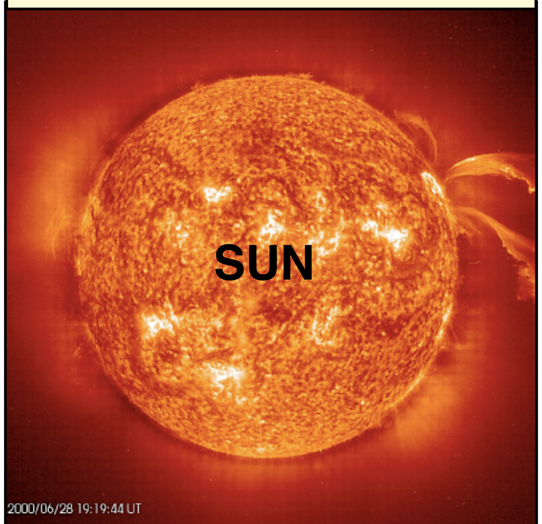
Lawrence Livermore National Lab

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344

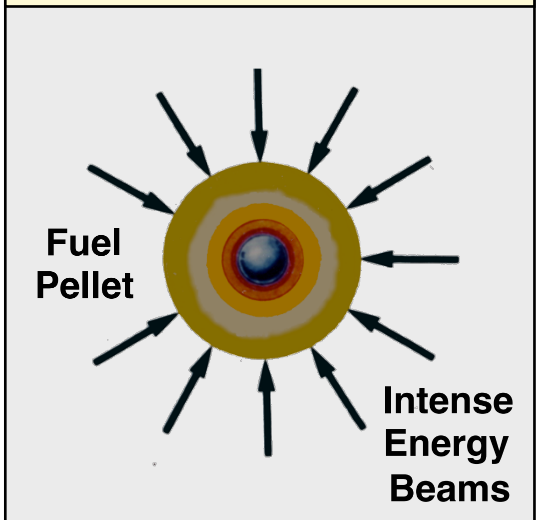
Fusion can be accomplished in three different ways

Gravitational Confinement



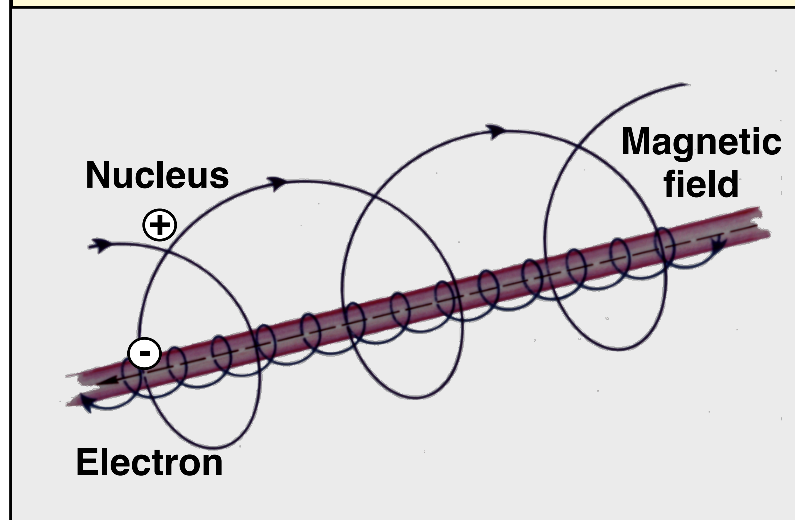
High density for billions of years

Inertial Confinement



High density for less than a billionth of a second

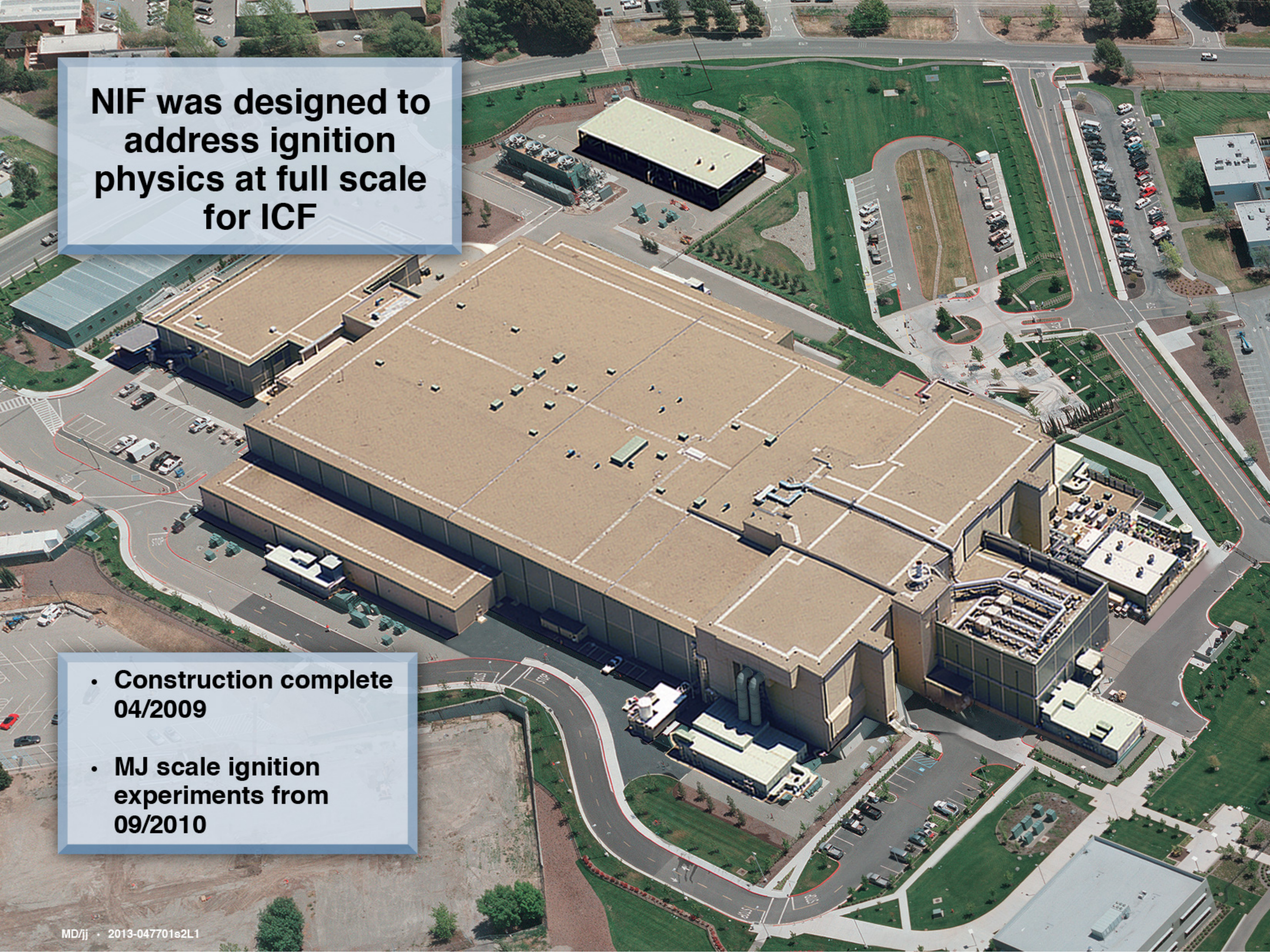
Magnetic Confinement



Low density for seconds

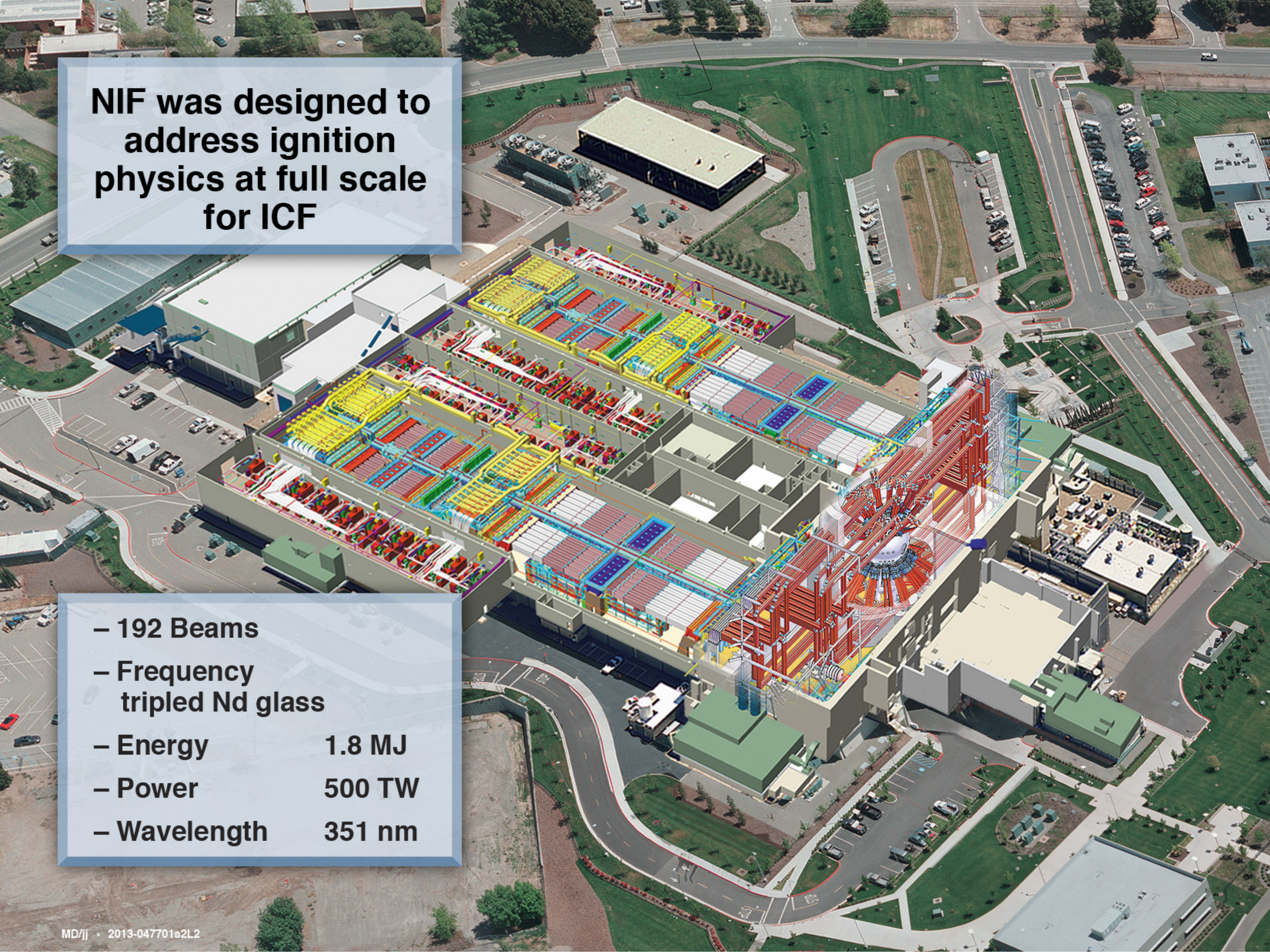
This talk describes our progress in inertial confinement

NIF was designed to address ignition physics at full scale for ICF



- **Construction complete 04/2009**
- **MJ scale ignition experiments from 09/2010**

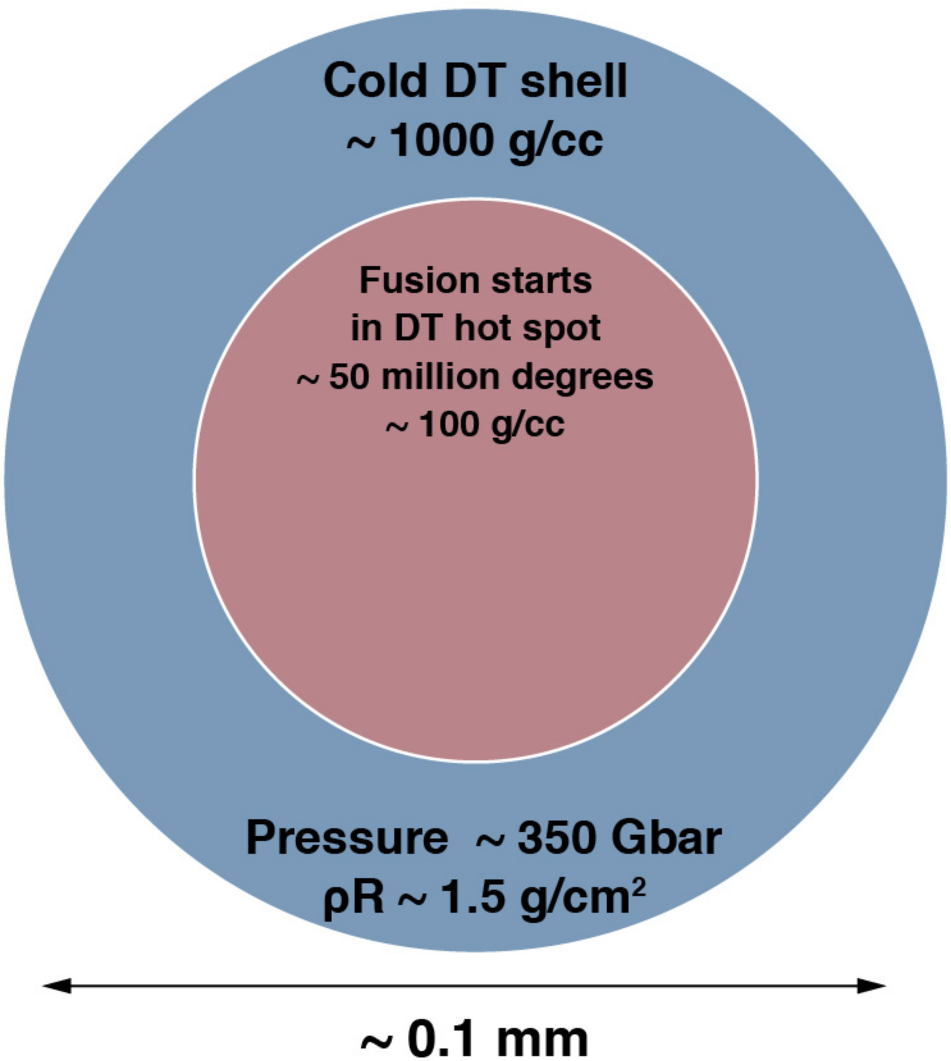
NIF was designed to address ignition physics at full scale for ICF



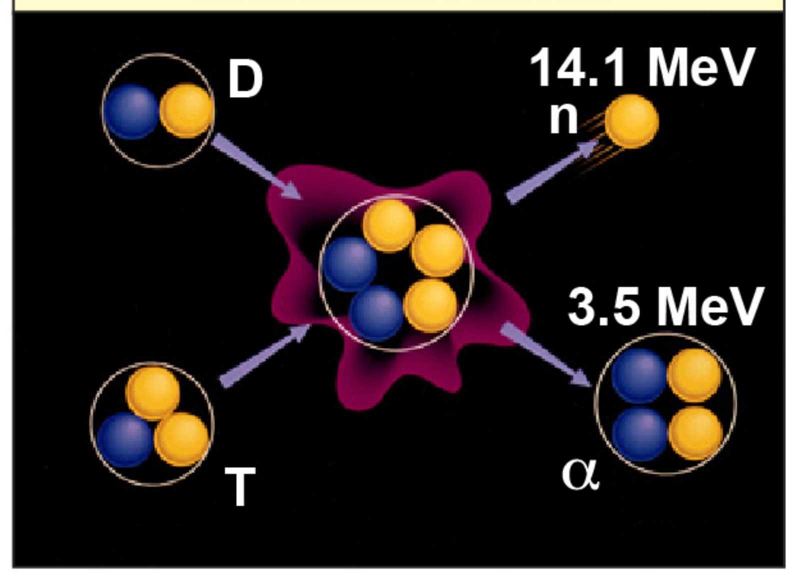
- 192 Beams
- Frequency tripled Nd glass
- Energy 1.8 MJ
- Power 500 TW
- Wavelength 351 nm

Ignition on NIF requires extremes in density and temperature

Deuterium-Tritium (DT) fuel



DT is ~ 100X more reactive than any other fusion reaction



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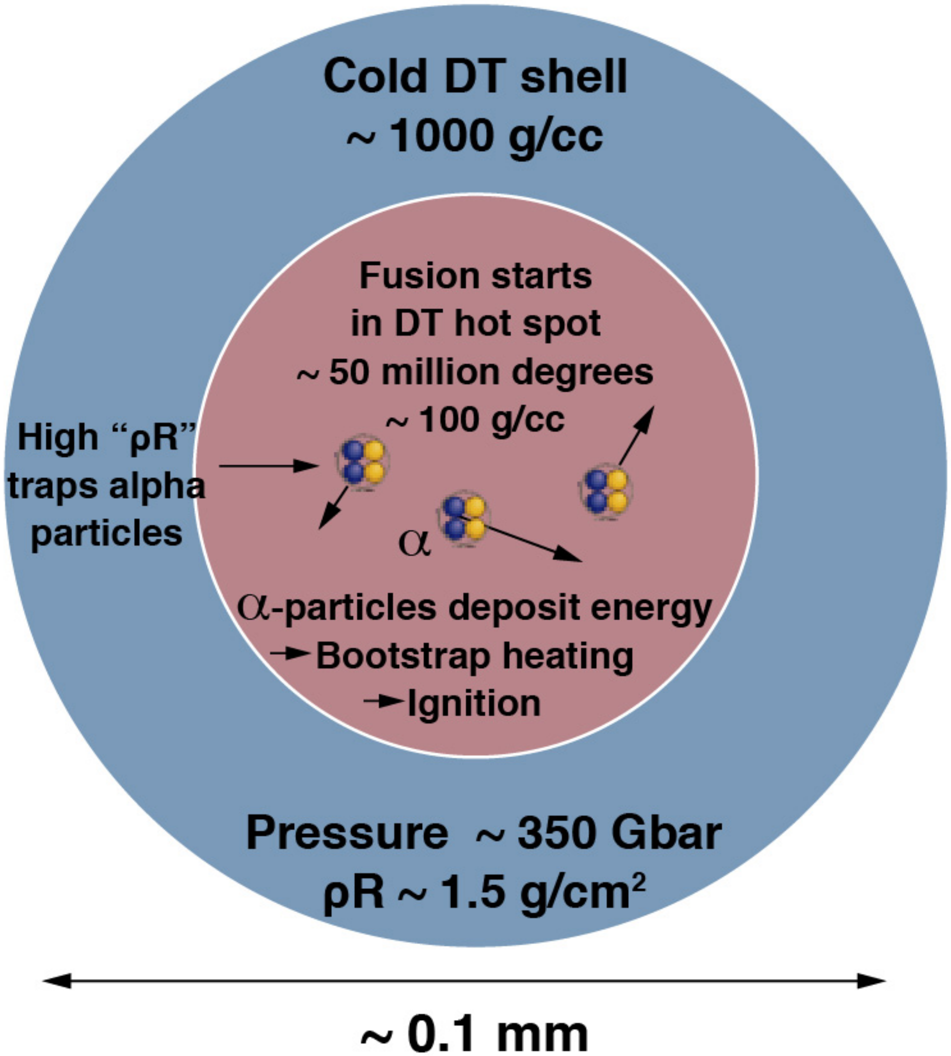

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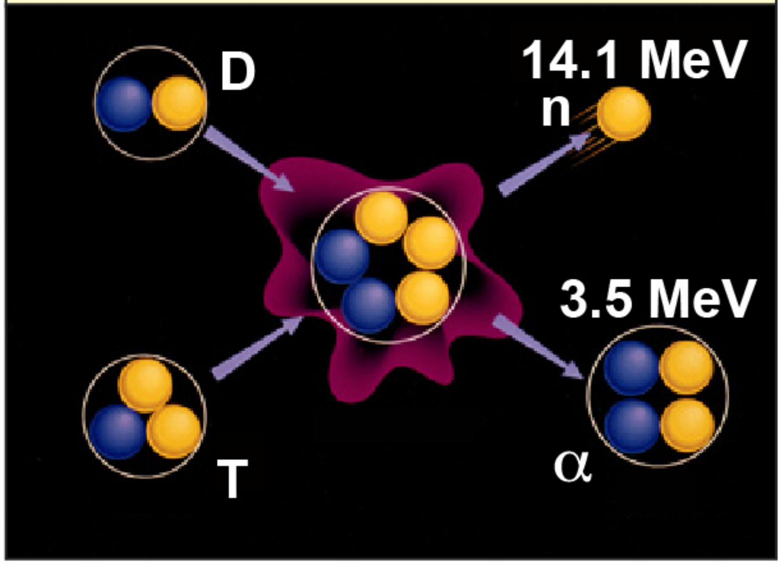
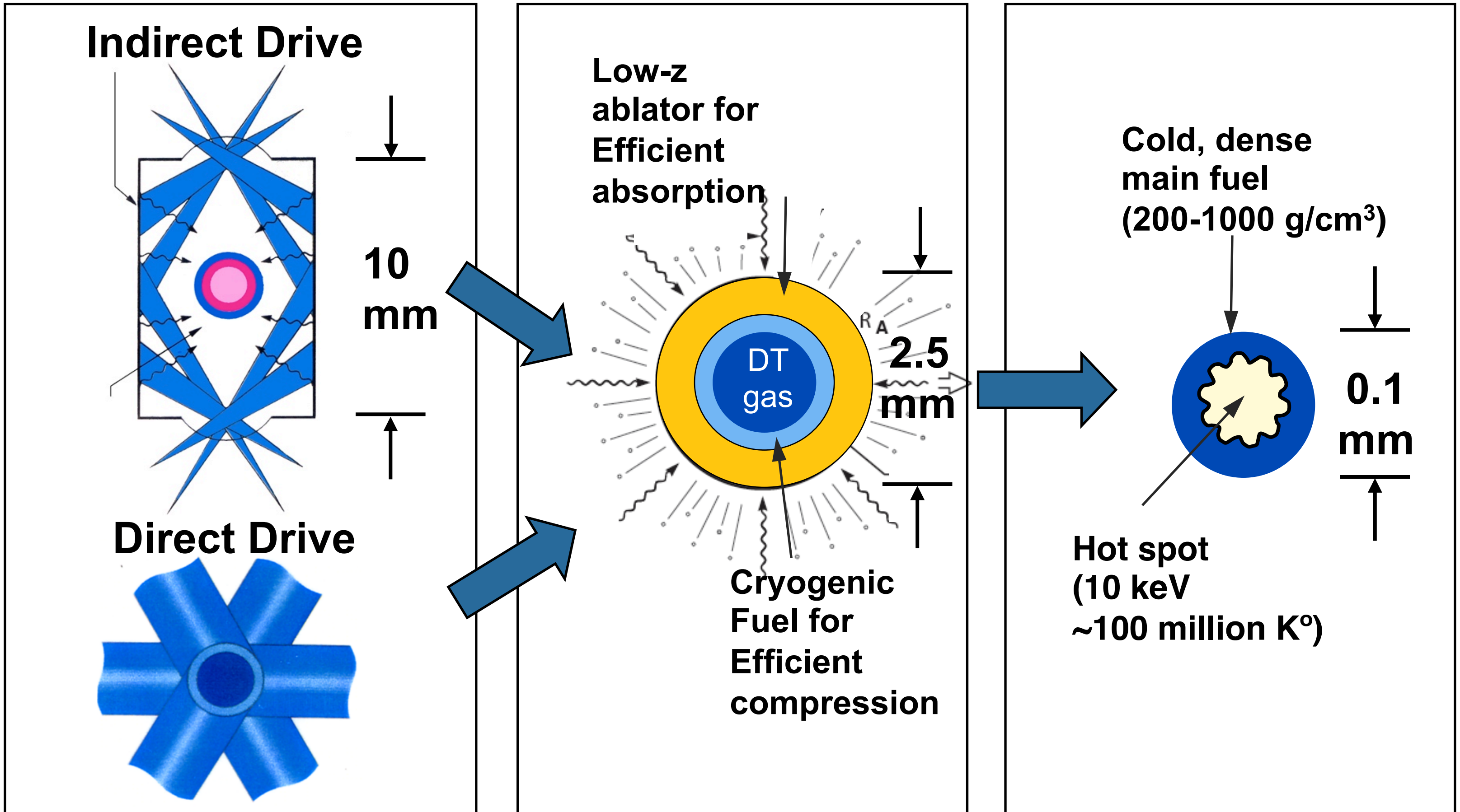


There are two principal approaches to compression in Inertial Confinement Fusion

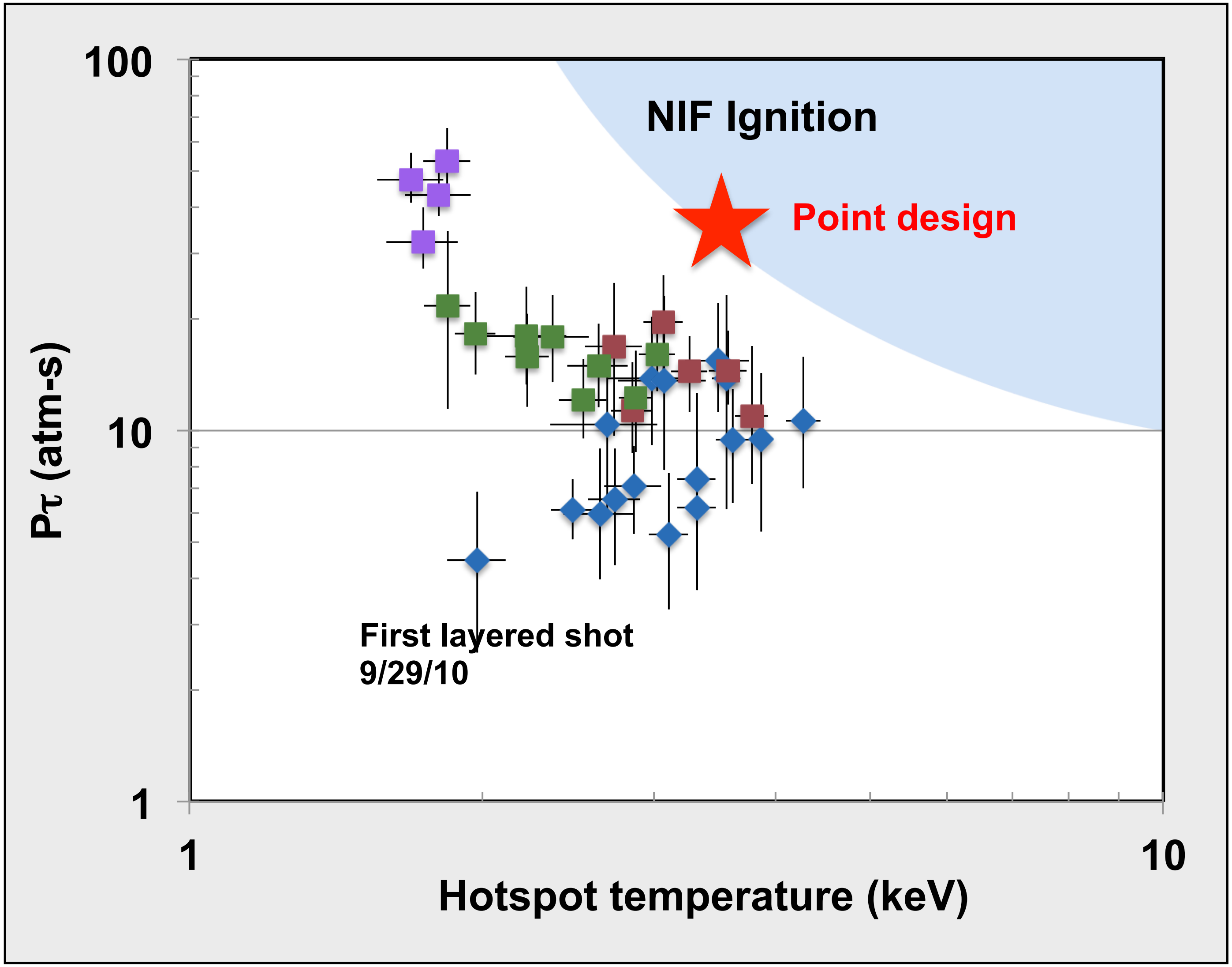


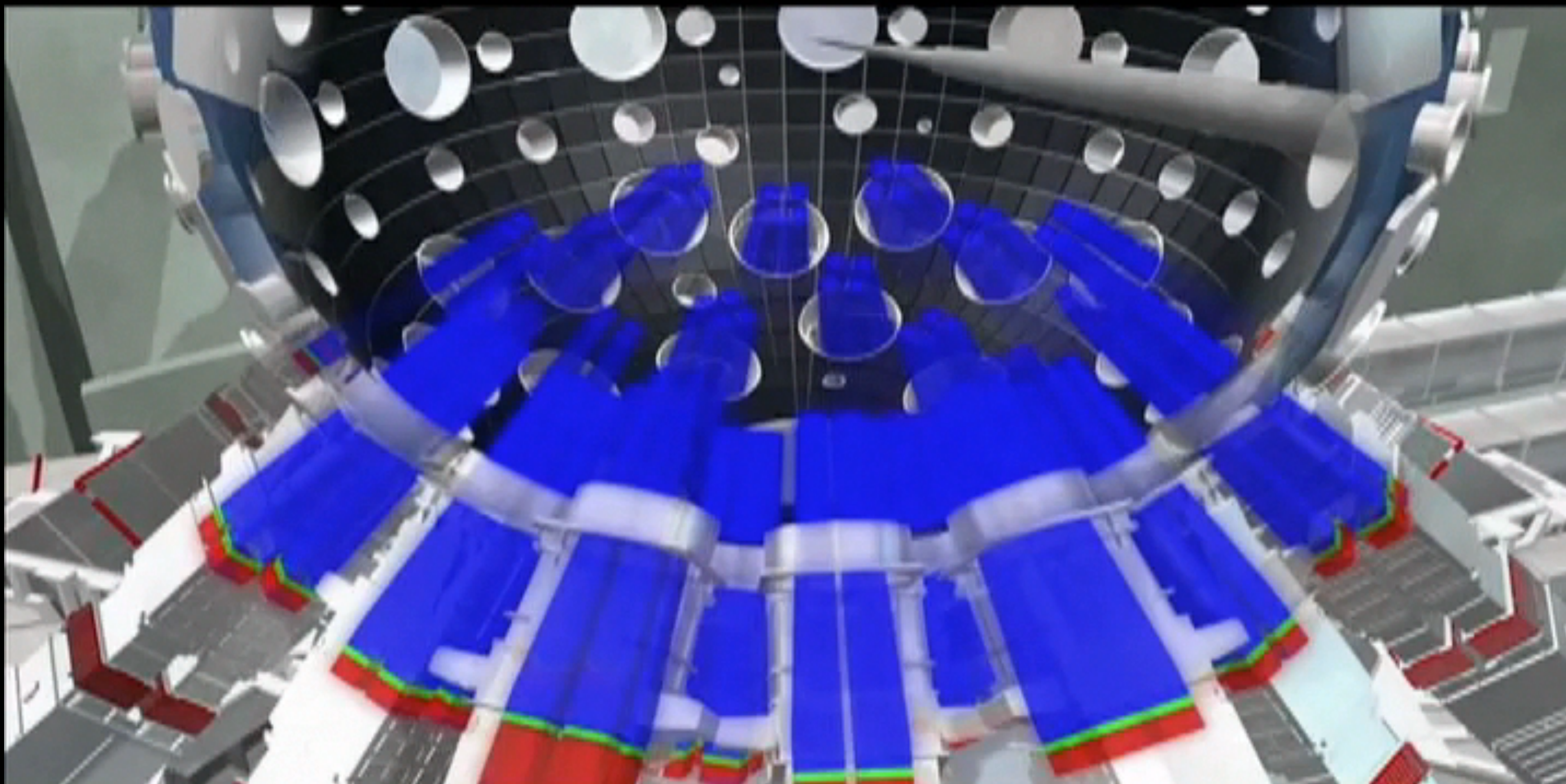
Rocket-like implosion achieves velocities of nearly 1 million MPH

Spherical collapse produces high temperatures and densities

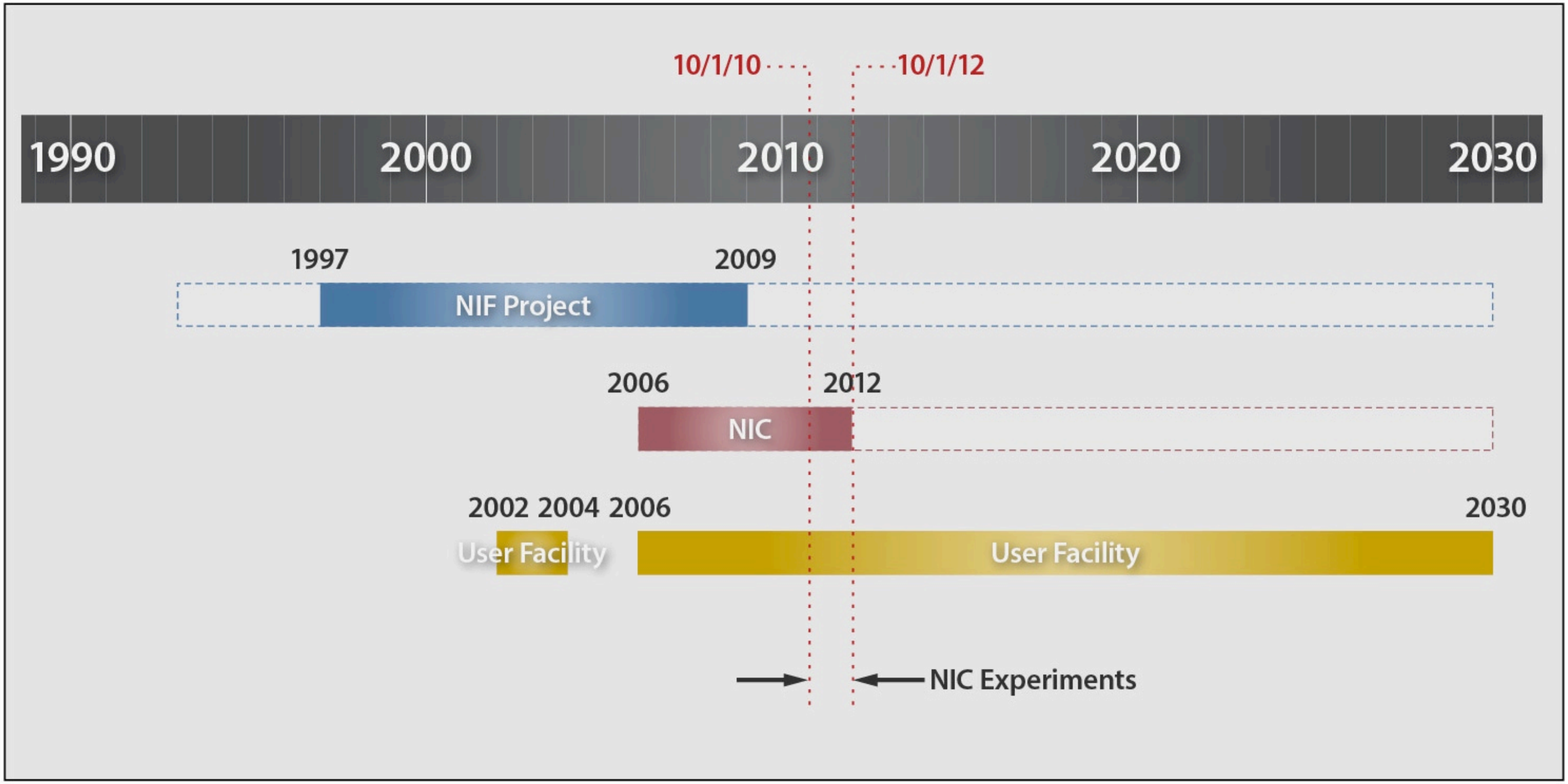
This talk focuses on Indirect Drive

Indirect drive on the NIF is within a factor of 2-3 of the conditions required for ignition





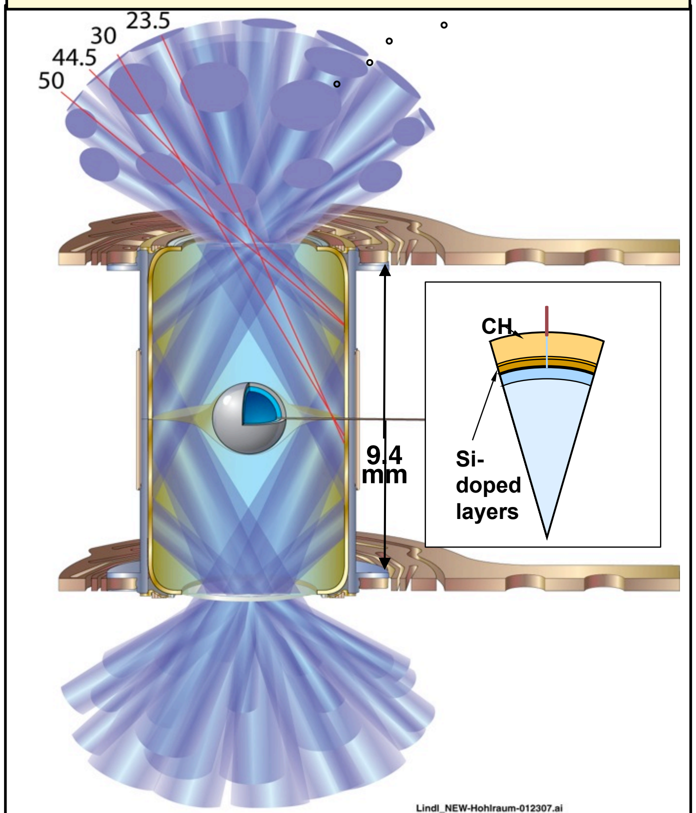
Story of NIF and Ignition



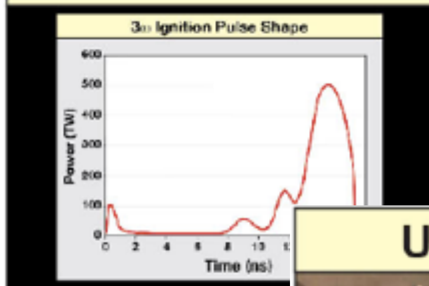
The National Ignition Campaign (NIC) has made strong progress towards ignition and initiated operation of NIF as the world's premier HED science facility

The ignition point design drove demanding technical requirements

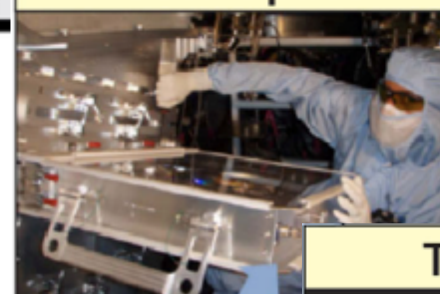
Doped plastic cryogenic layered point design



NIF Laser



User Optics



Target Fab

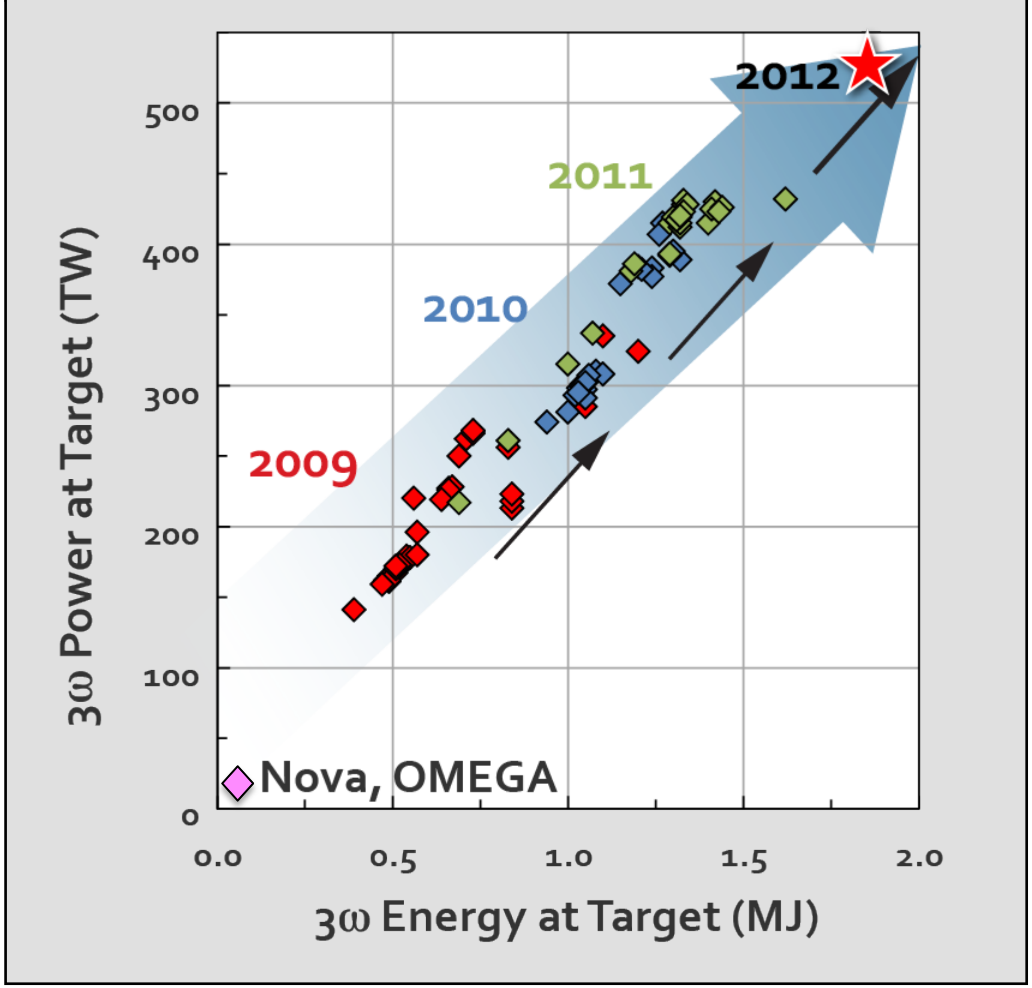
Diagnostics

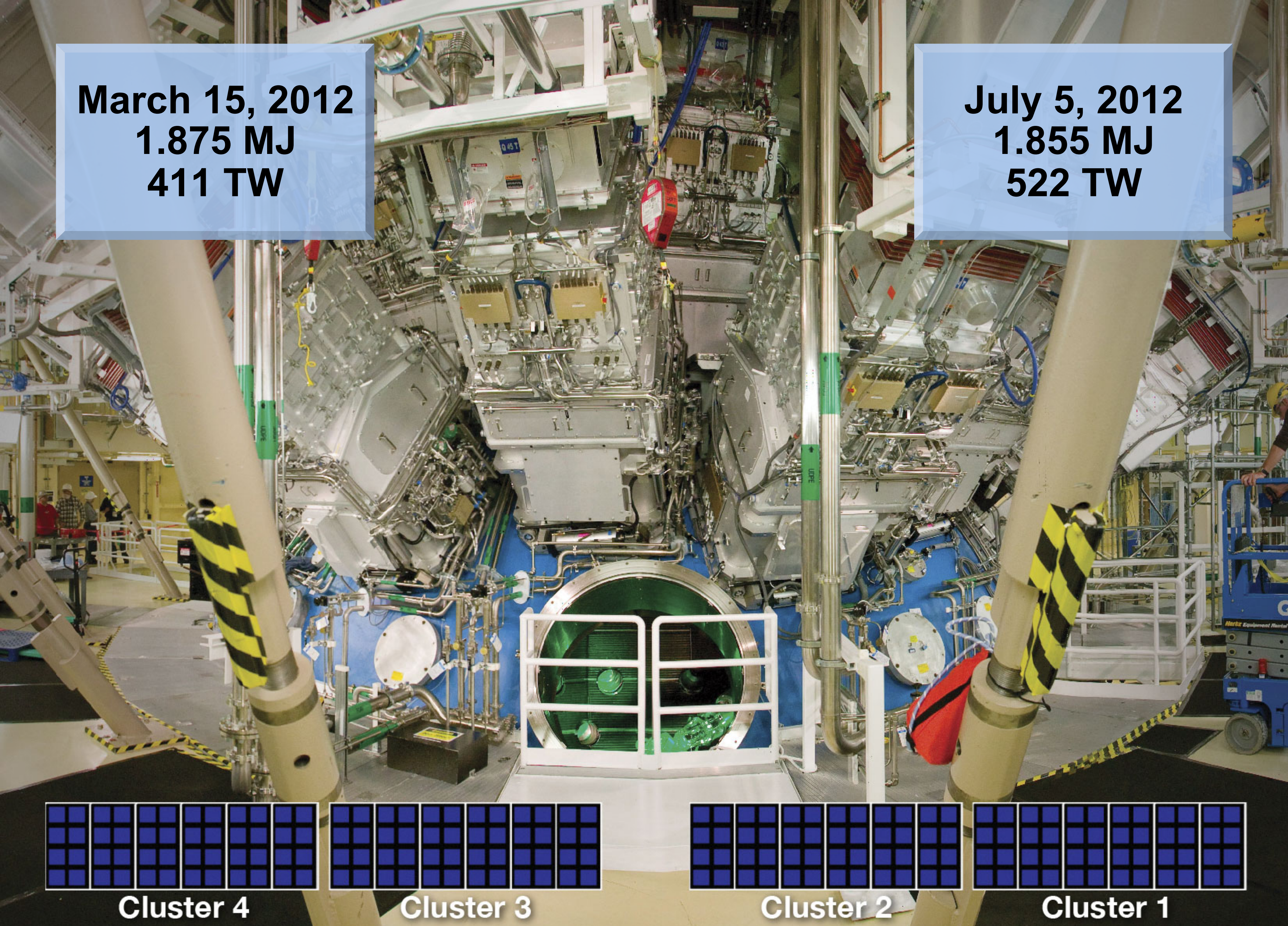
We have met these requirements

NIF operational capabilities — laser energy/power

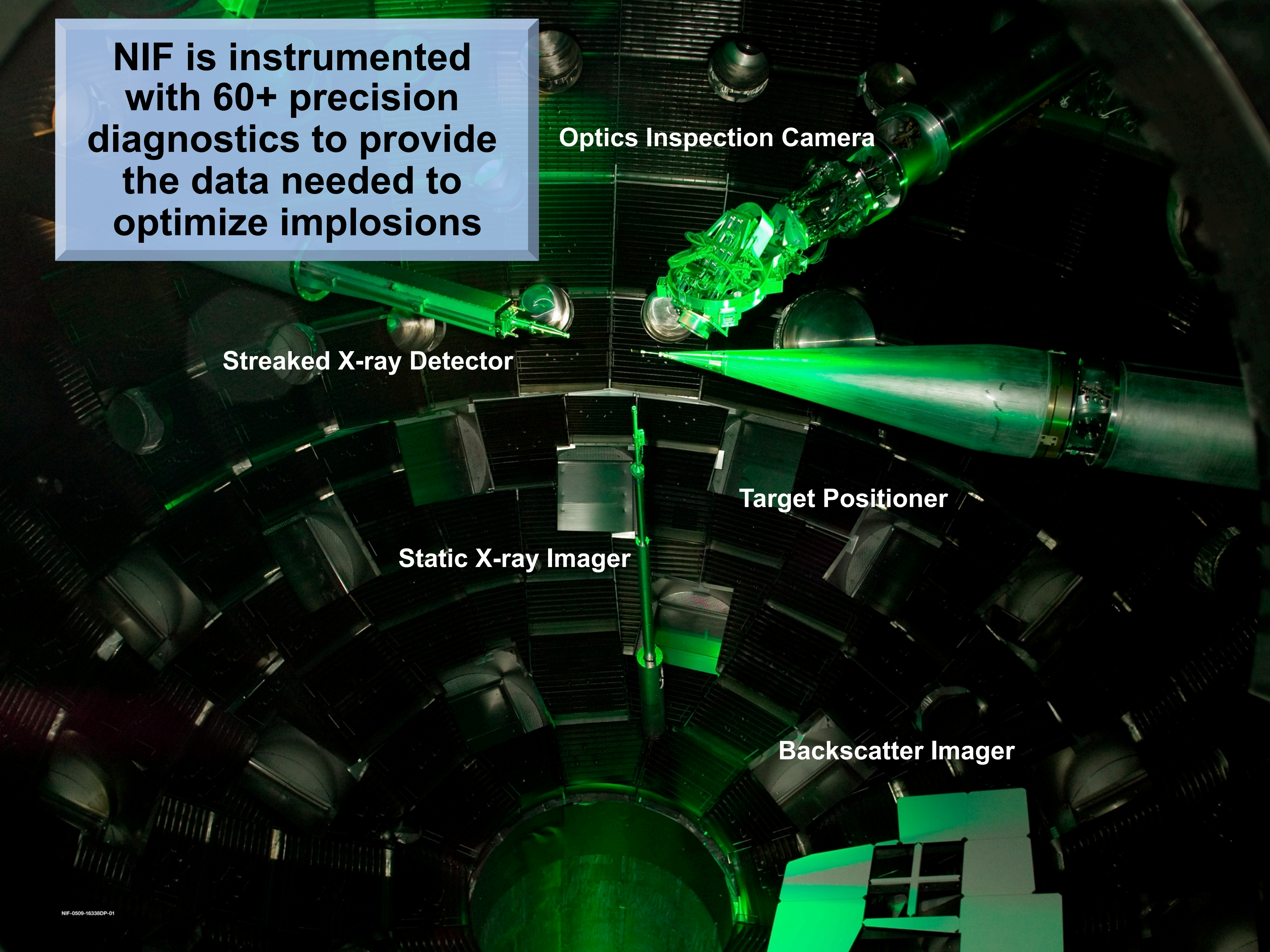
- NIF laser is steadily increasing NIF has now achieved its 1.8 MJ milestone, with a power of 522 TW in an ignition pulse format
- Operation at over 9 J/cm^2 at 3ω
- The NIF has intrinsic capability to continue on this growth path for several more years

Increase in energy roughly 10kJ/week, now exceeding the original NIF specifications (1.8 MJ / 500TW)

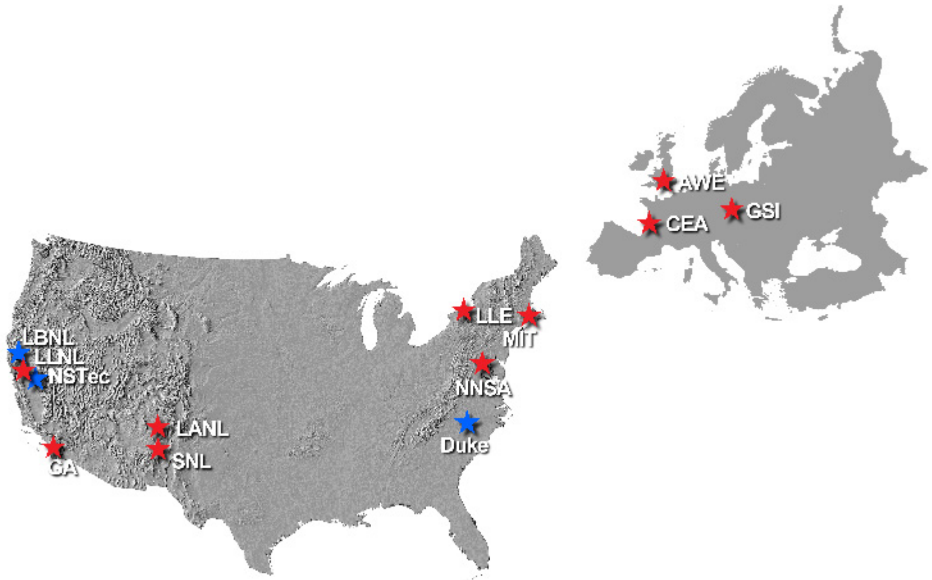



March 15, 2012
1.875 MJ
411 TW
July 5, 2012
1.855 MJ
522 TW
Cluster 4
Cluster 3
Cluster 2
Cluster 1

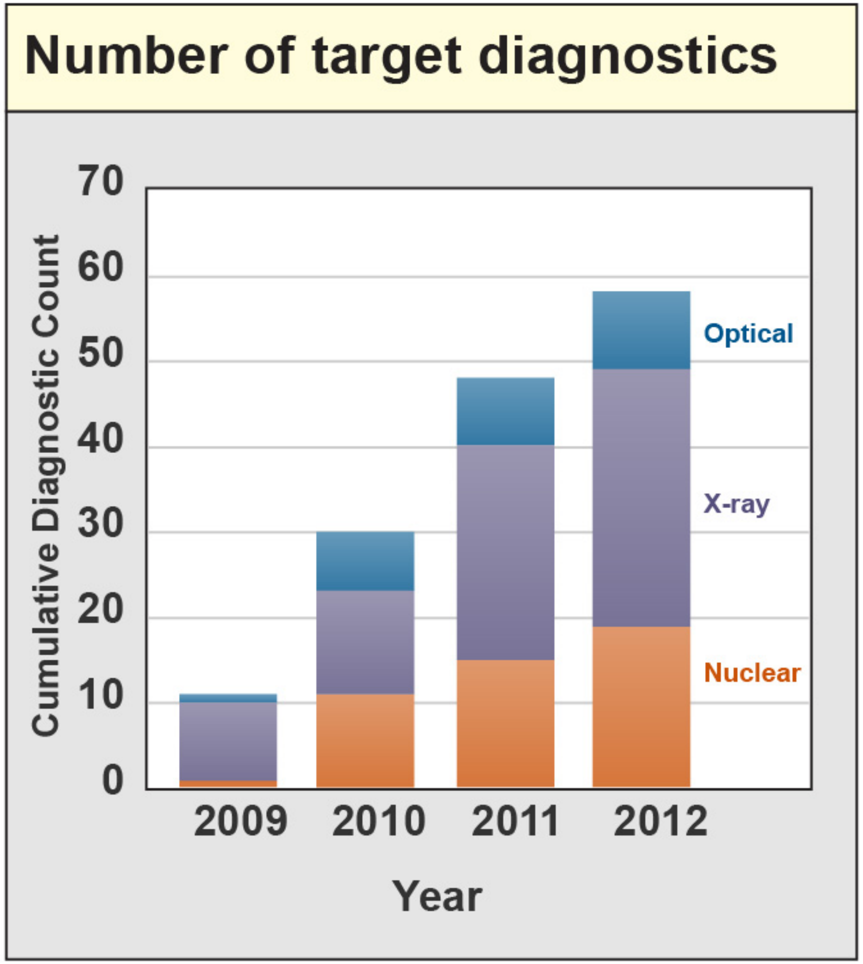
NIF is instrumented with 60+ precision diagnostics to provide the data needed to optimize implosions



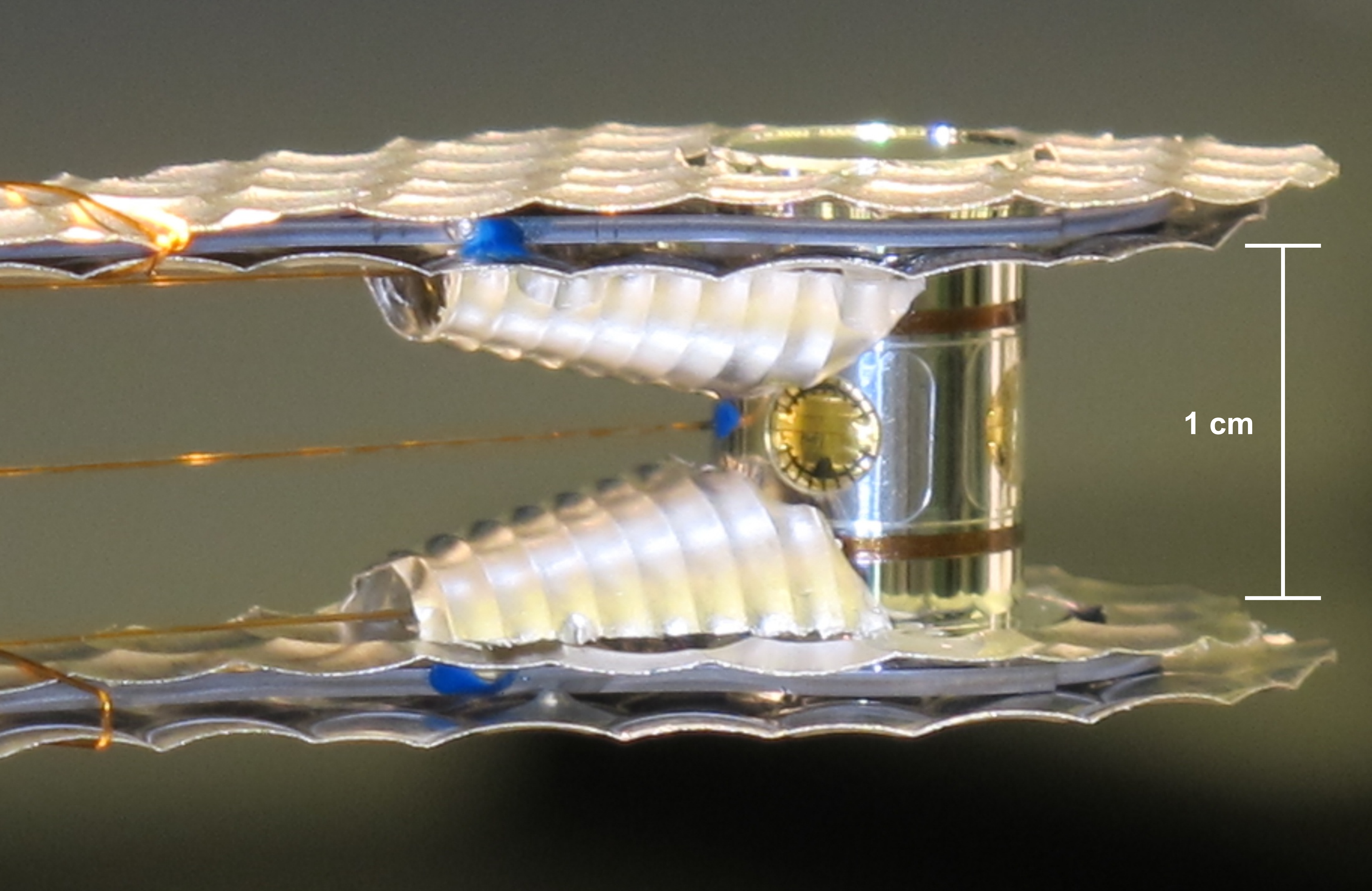
60 target diagnostics enable cutting edge science on the NIF



- LLNL
- LANL
- LLE
- NSTec
- U of M
- LBNL
- AWE
- MIT
- CEA
- Duke
- SNL
- GSI

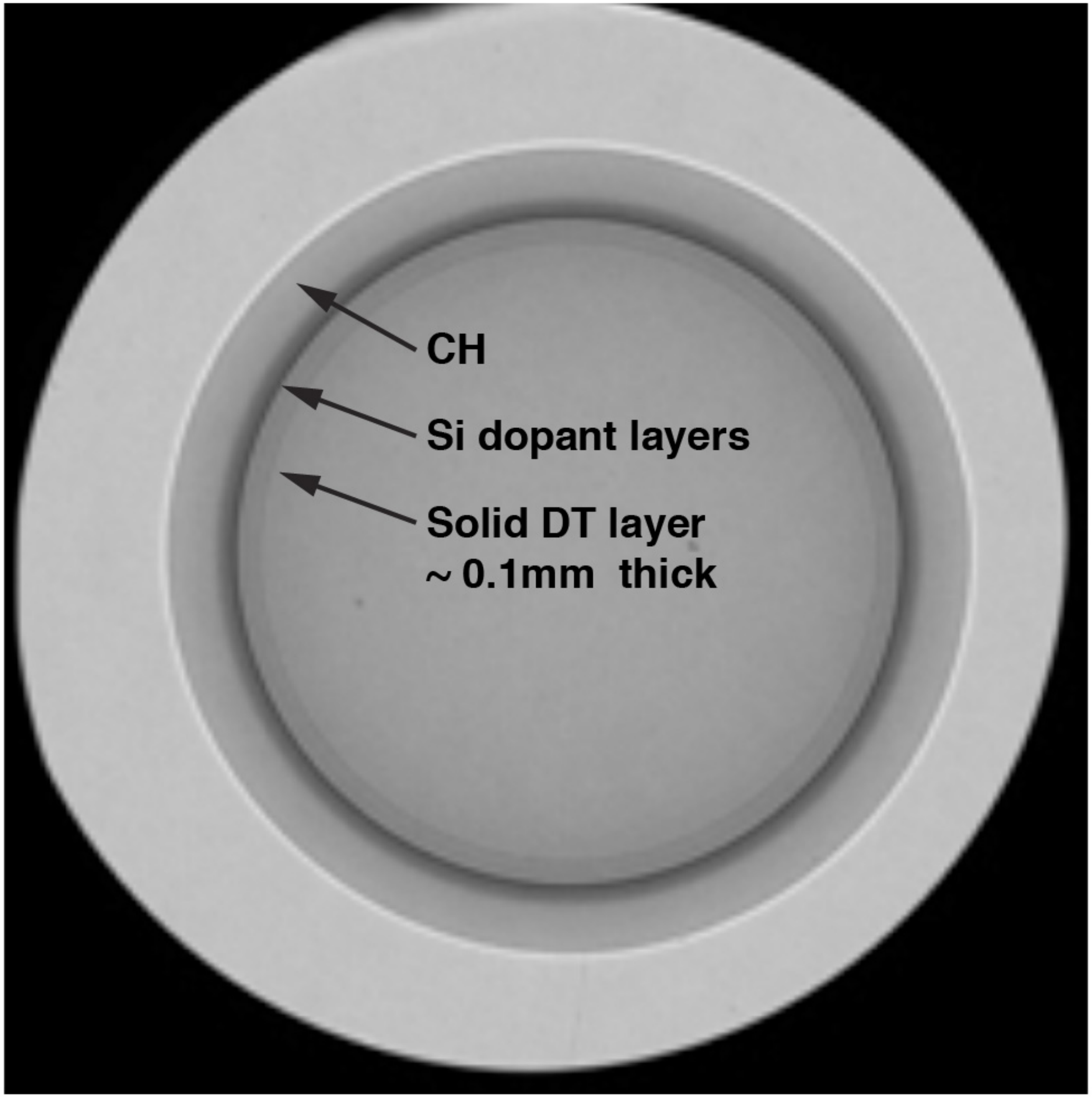


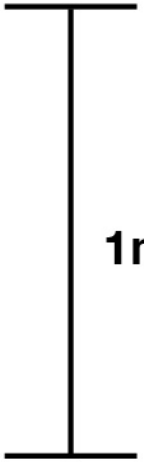
Over 15 universities participating in the science program



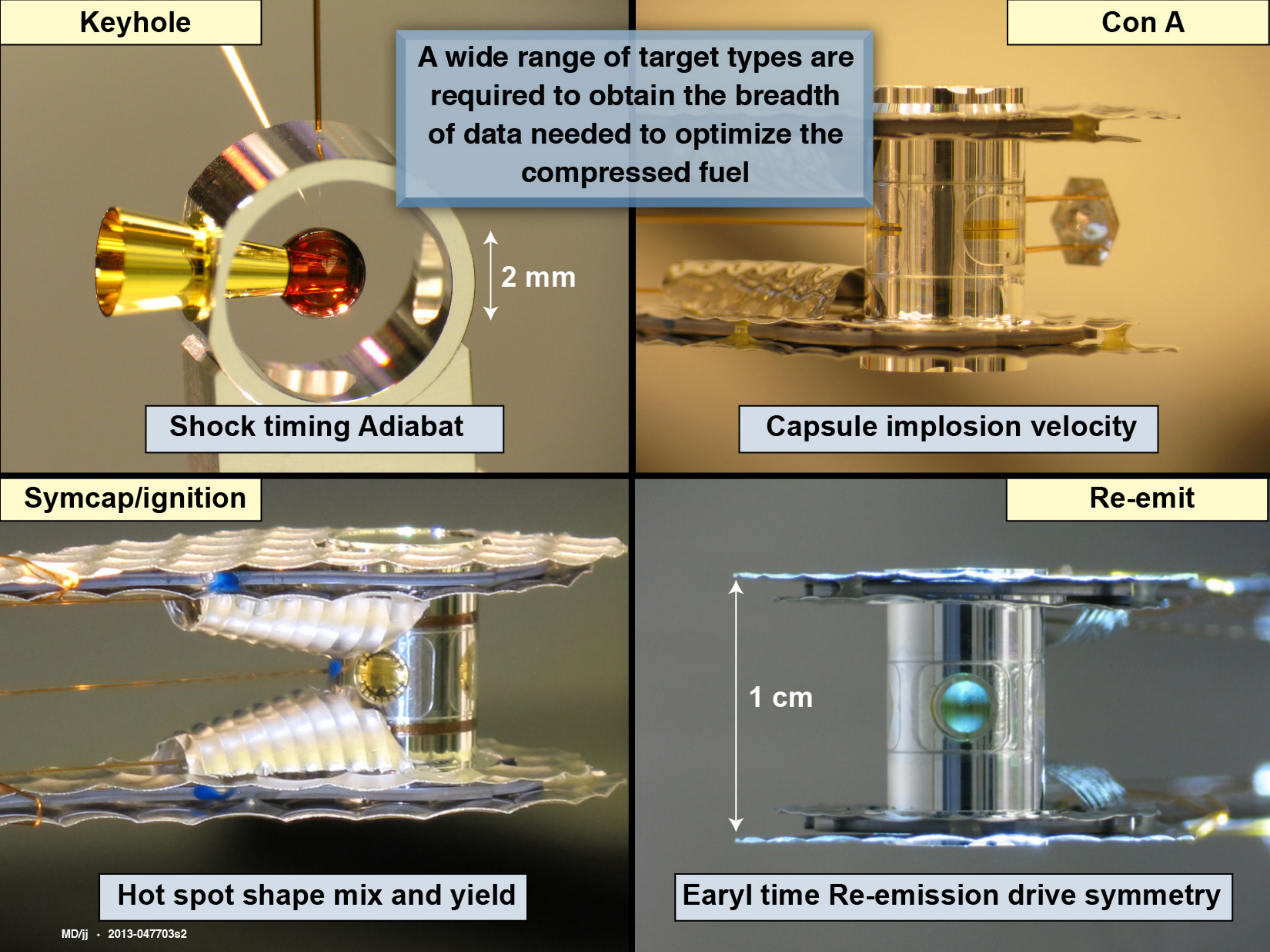
Target is the "fusion system" which can be modified on every shot

We can now build capsules that meet ignition target specifications



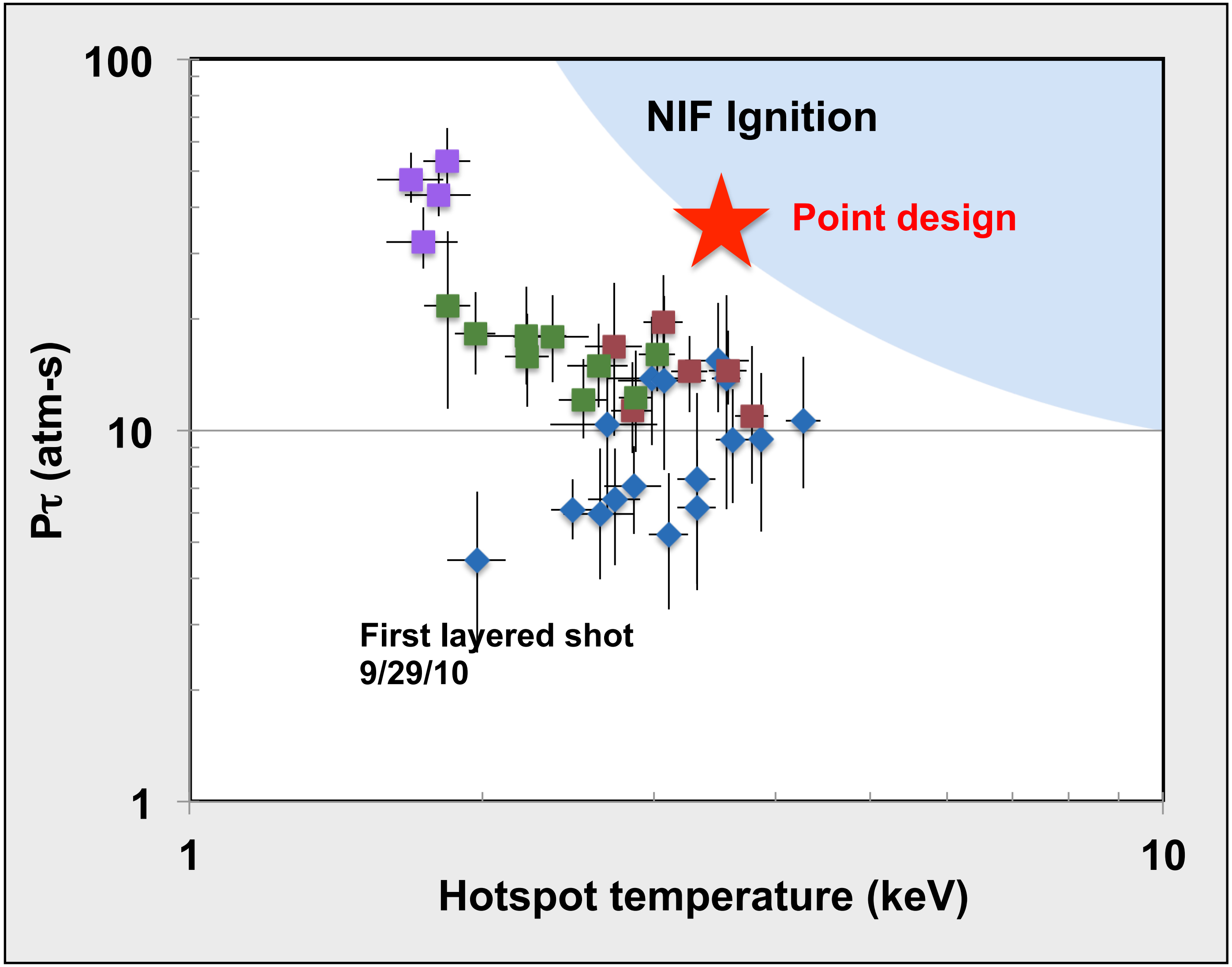


20nm surface finish

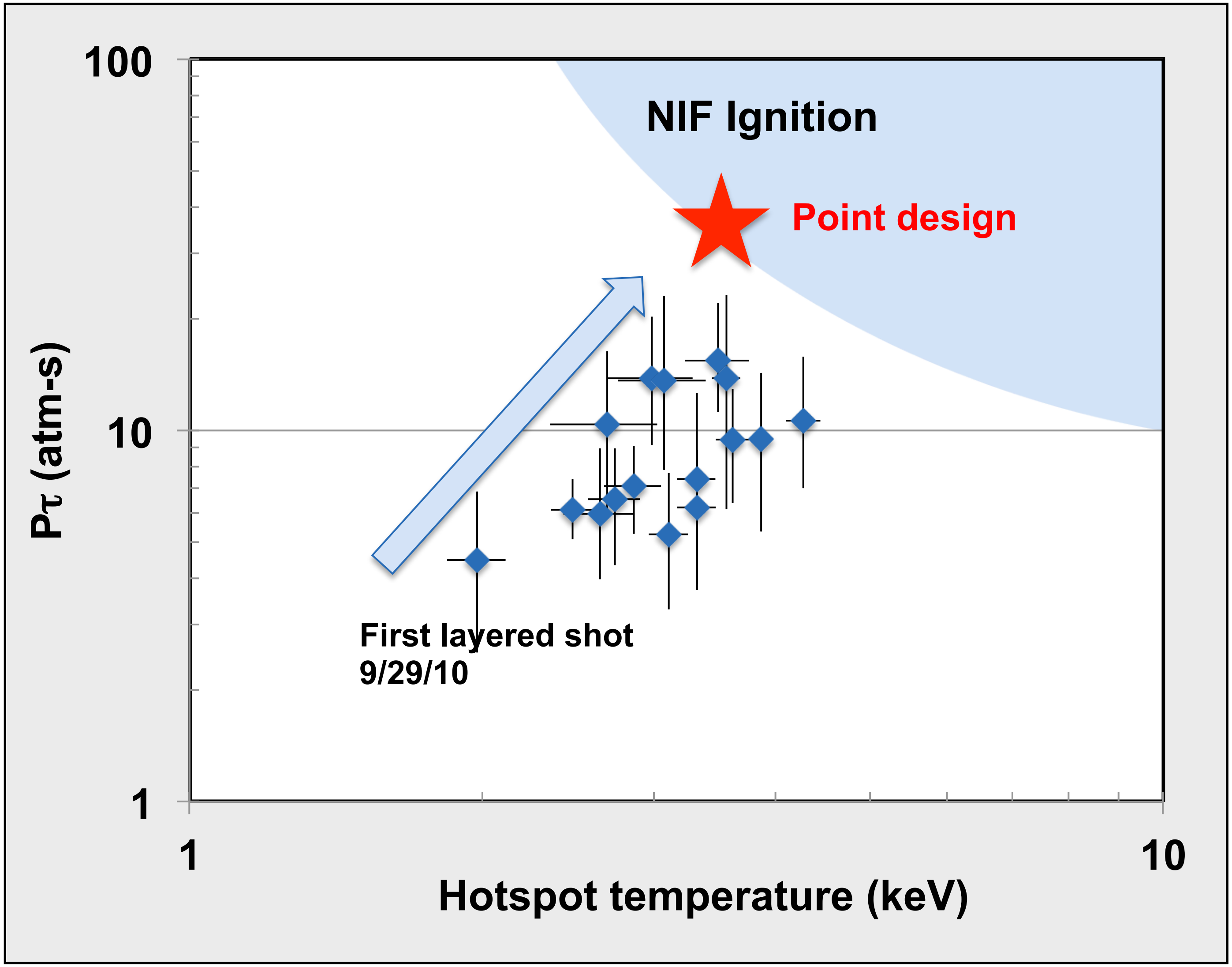


A wide range of target types are required to obtain the breadth of data needed to optimize the compressed fuel
Keyhole
2 mm
Shock timing Adiabat
Con A
Capsule implosion velocity
Symcap/ignition
Hot spot shape mix and yield
Re-emit
1 cm
Earyl time Re-emission drive symmetry
MD/jj • 2013-047703s2

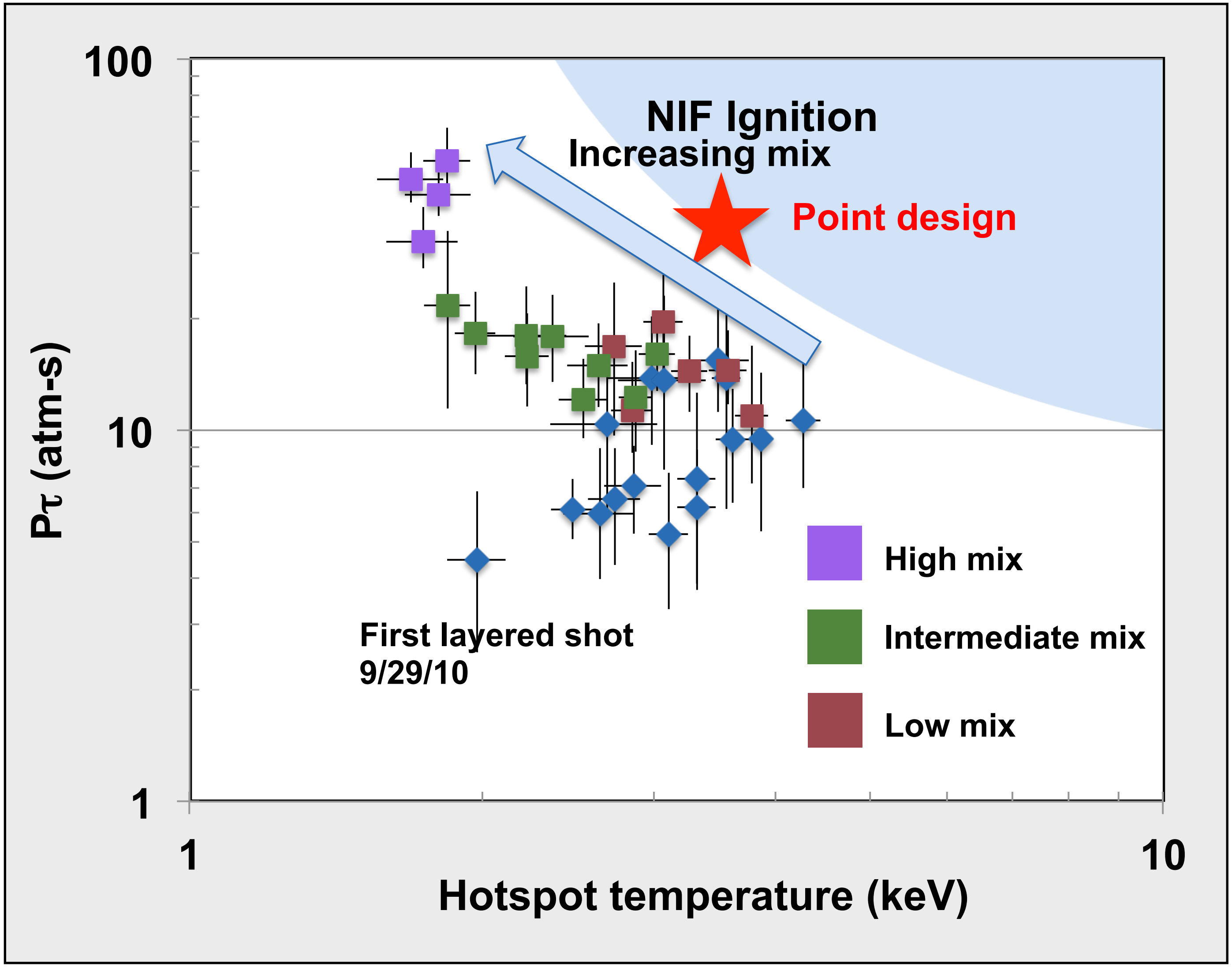
Indirect drive on the NIF is within a factor of 2-3 of the conditions required for ignition



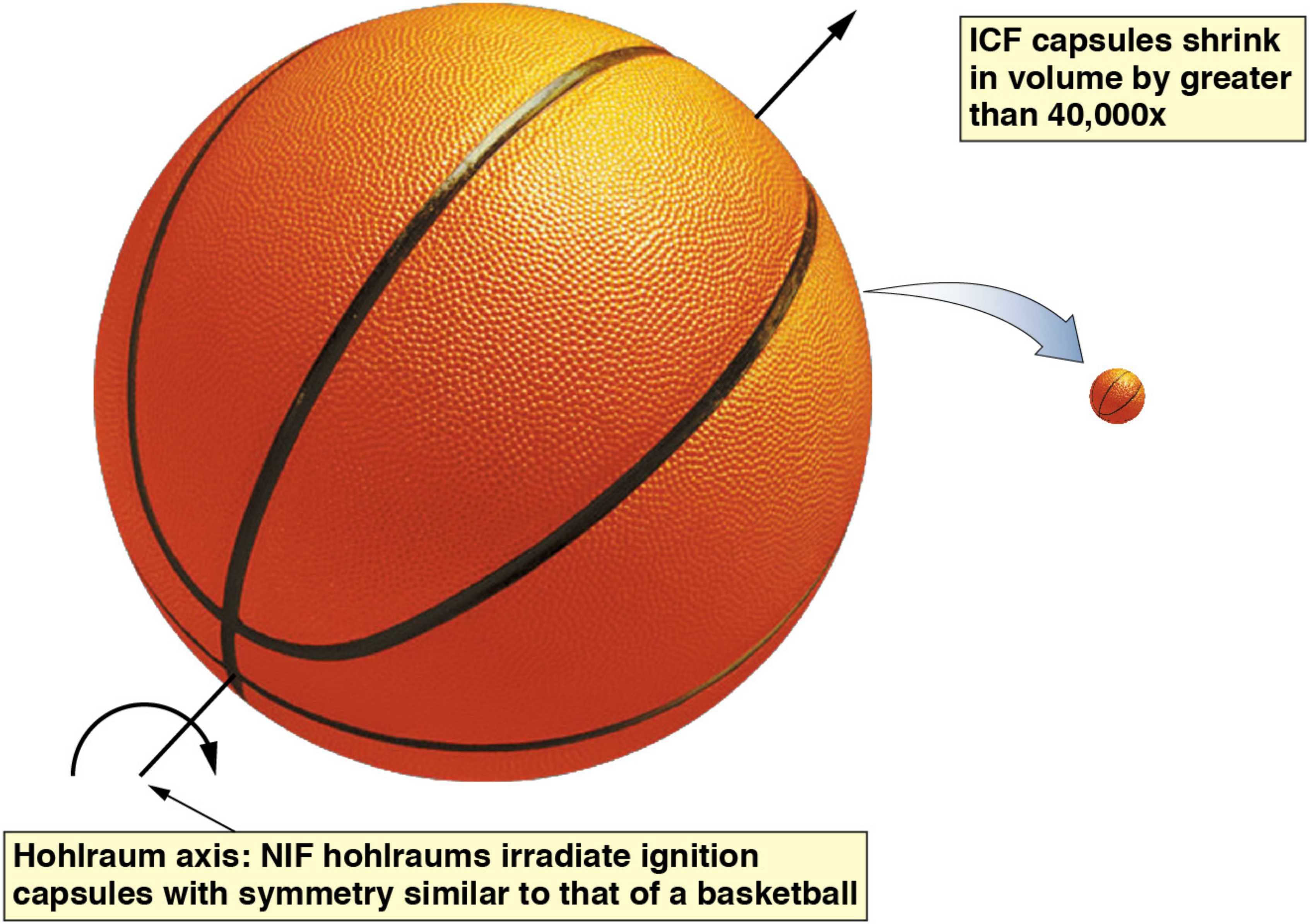
Shots in 2010-2011, with low laser drive and less compression, moved toward point design



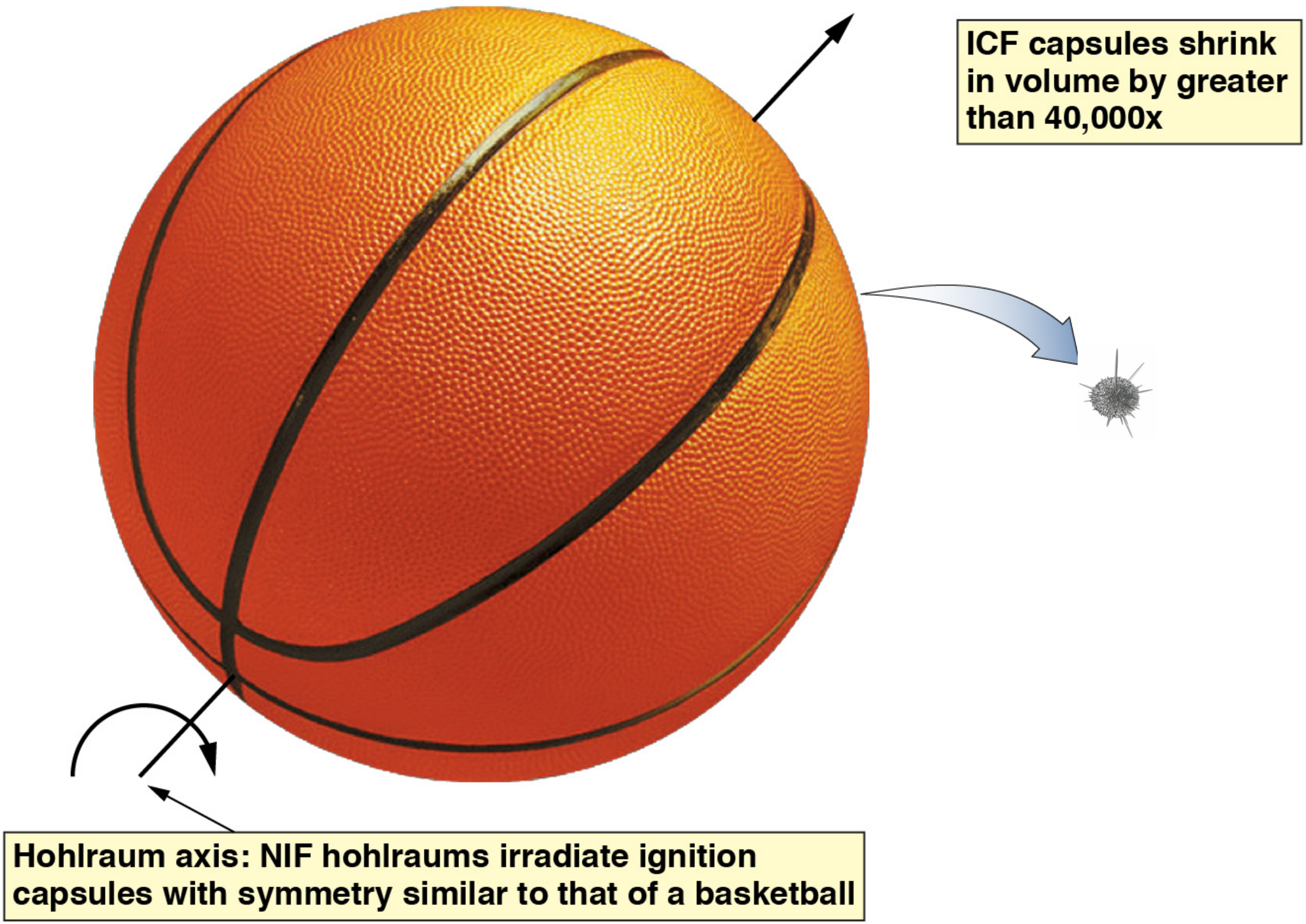
In 2012, higher compression and more laser drive resulted in CH mix into the hotspot



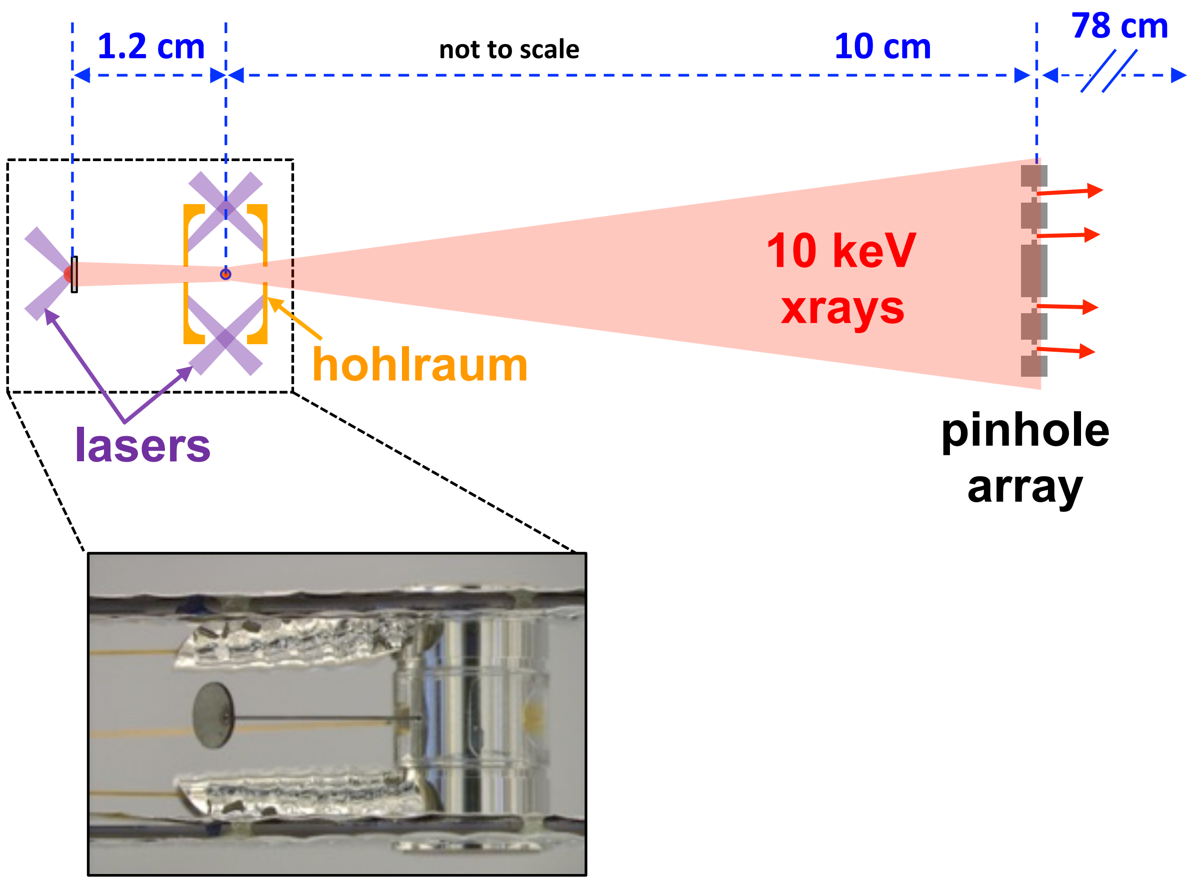
We believe some of the pressure deficit is due to nonspherical compression



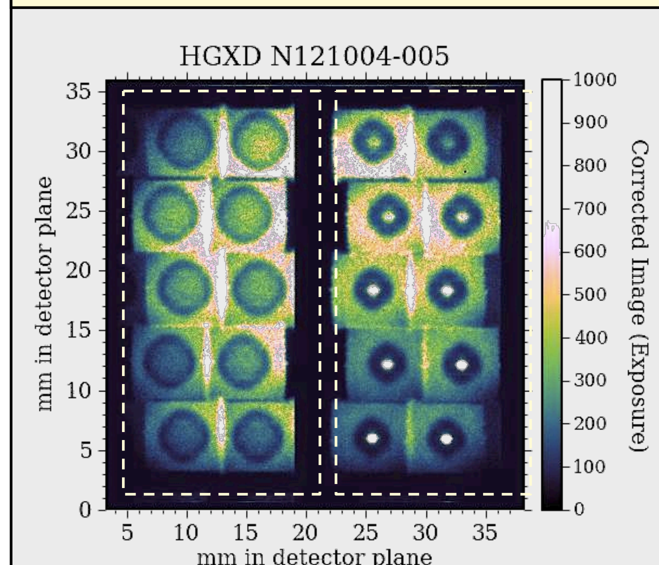
High convergence can lead to instability growth that "mixes" plastic into the fuel



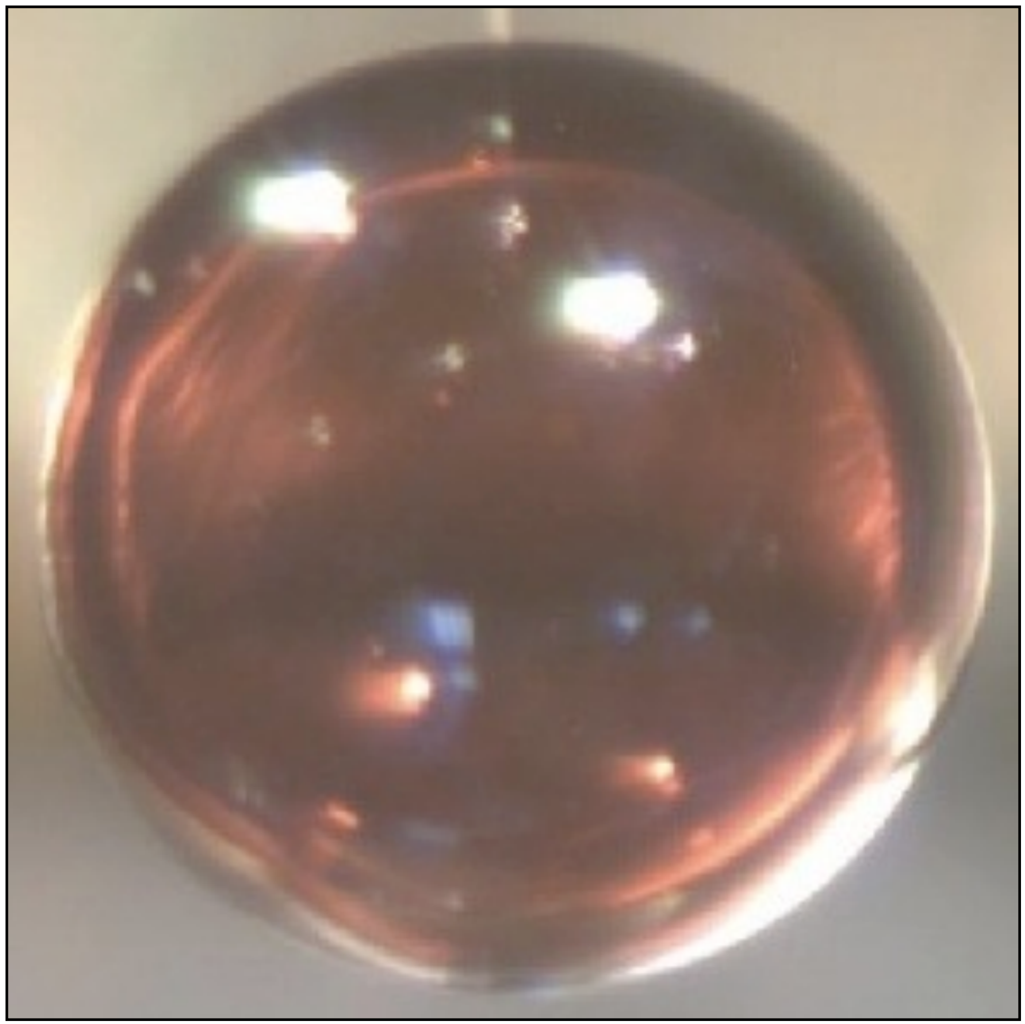
We have begun measuring fuel layer asymmetry inflight with backlit radiography



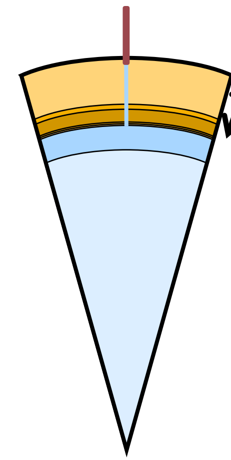
Gated images of imploding capsule on framing camera



The capsule starts at 2mm diameter

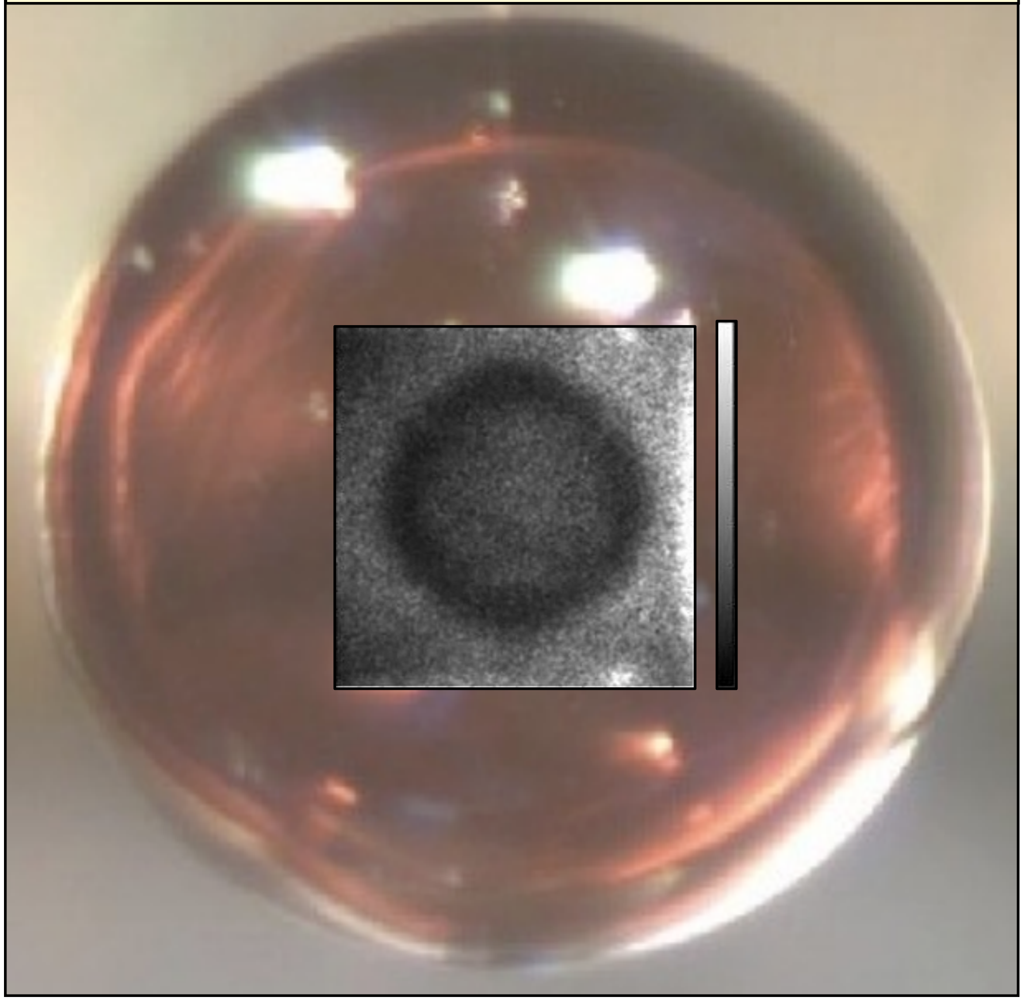


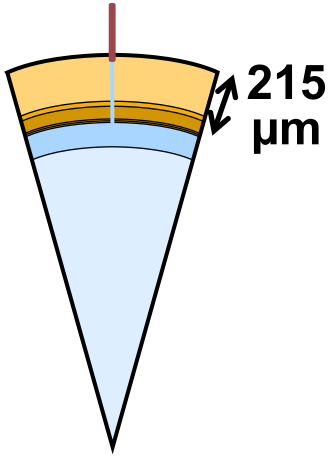
~2 mm



Images inflight show Legendre mode 4 "diamond" shape to fuel layer

NI21004
Bang time – 600ps



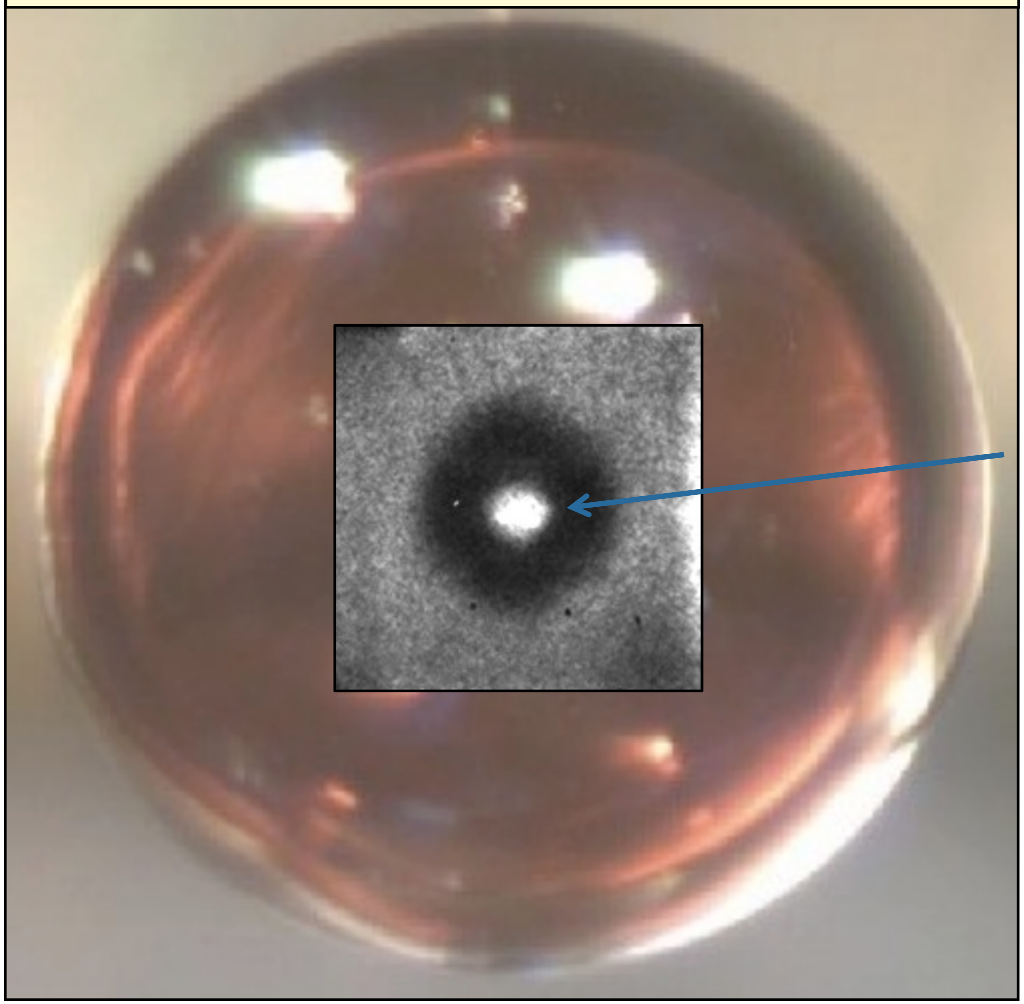


Legendre mode 4 asymmetry is corrected by 5-10% change in hohlraum length

300 ps later, we can see the hotspot begin to form

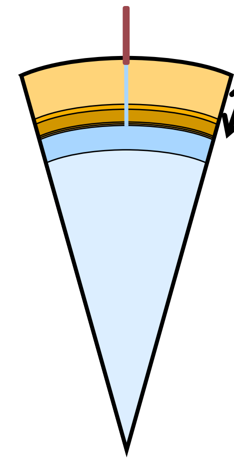
NI21004

Bang time – 300ps



Early hot spot formation

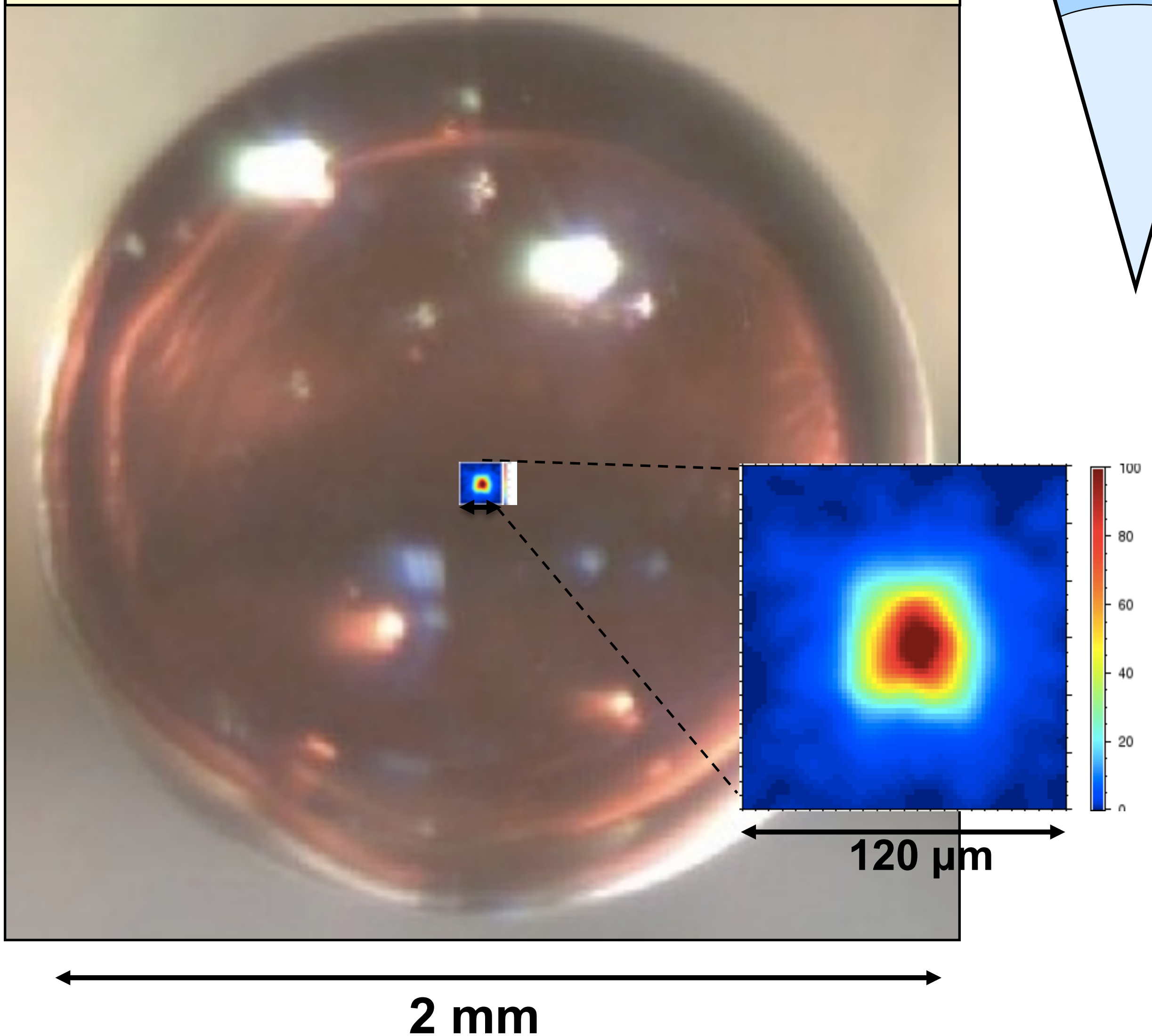
~2 mm

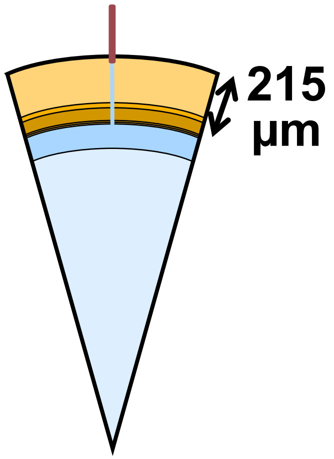


215 µm

Despite cold fuel asymmetry the hot spot looks quite round at peak emission

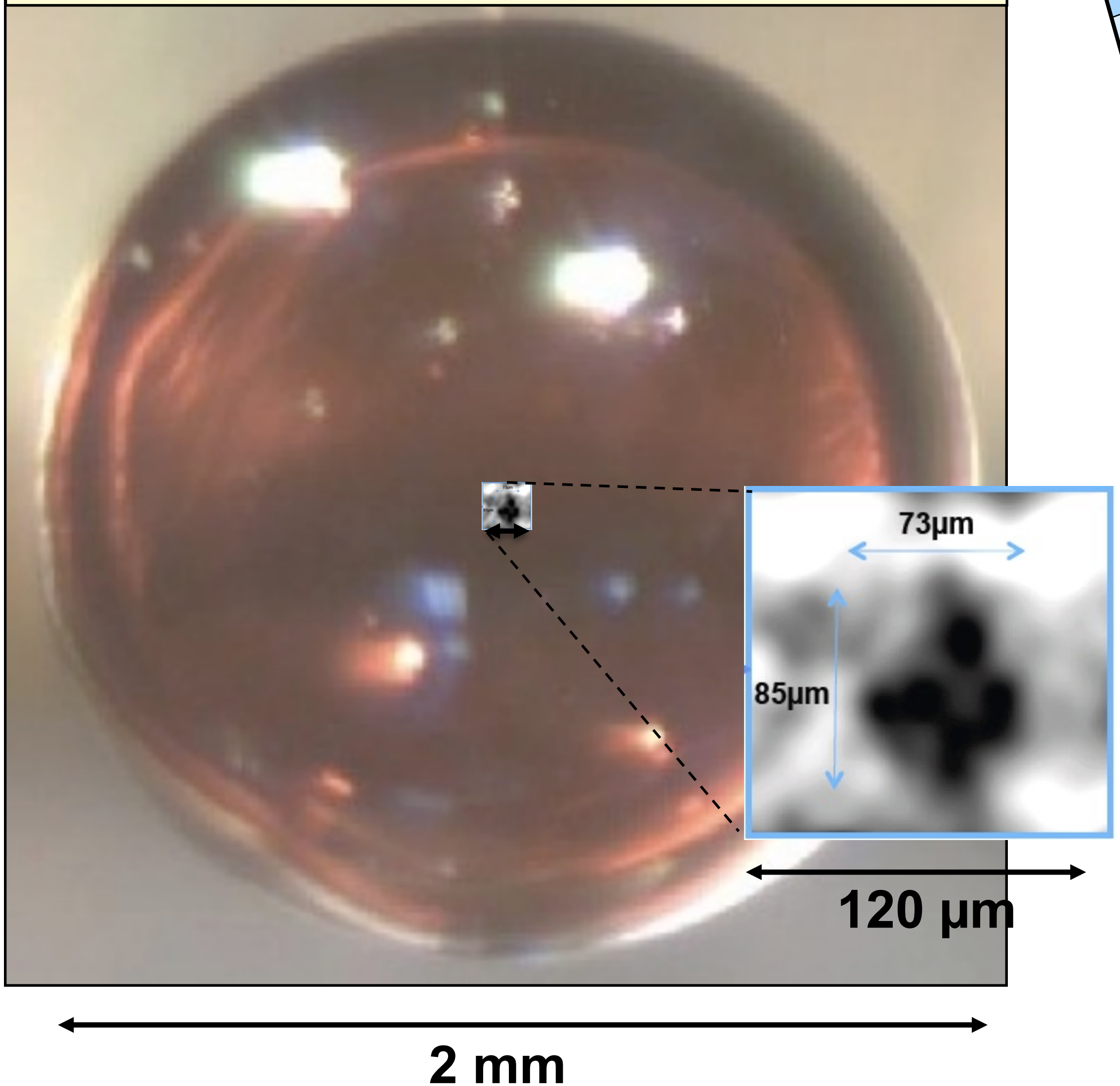
DT shot N120716
Bang time

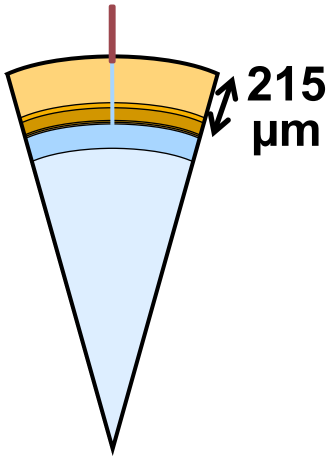




Most recent data (Oct-Dec 2012) probes fuel shape at stagnation

N121005
Bang time ± 50ps

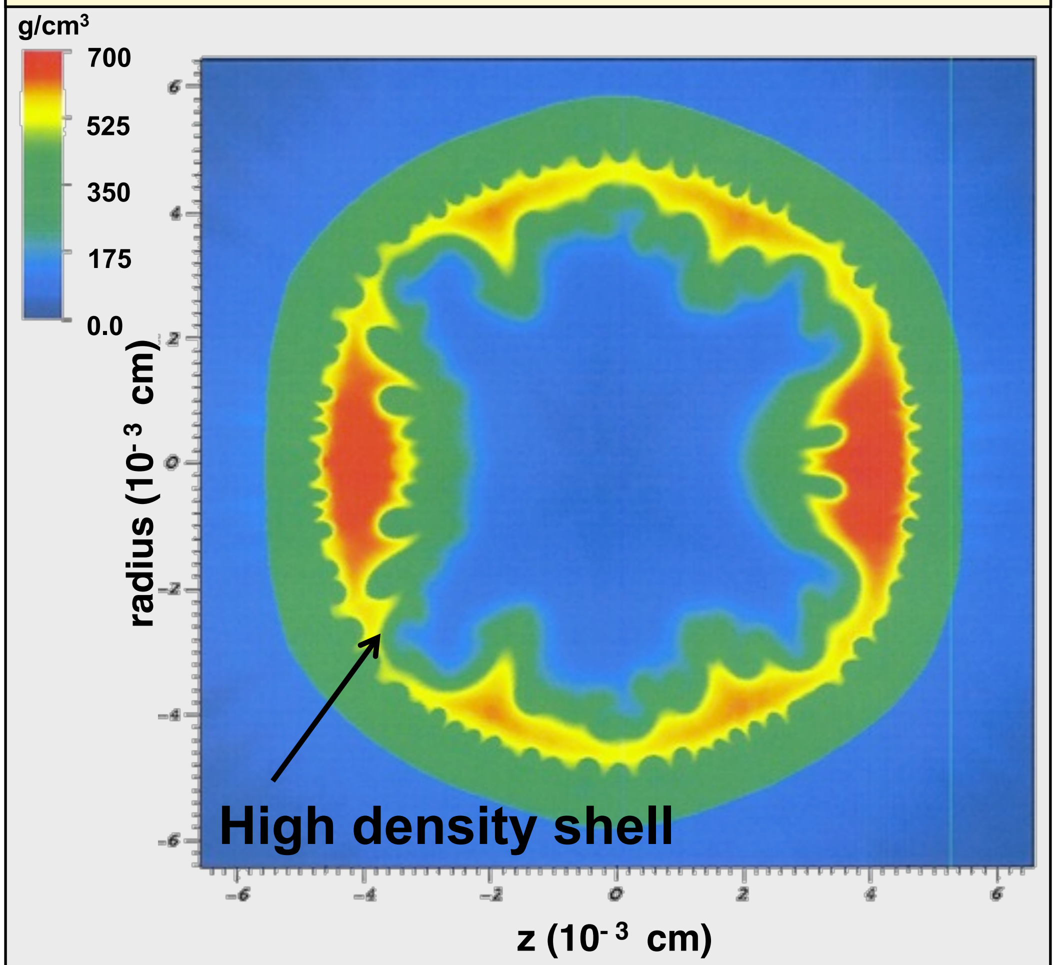




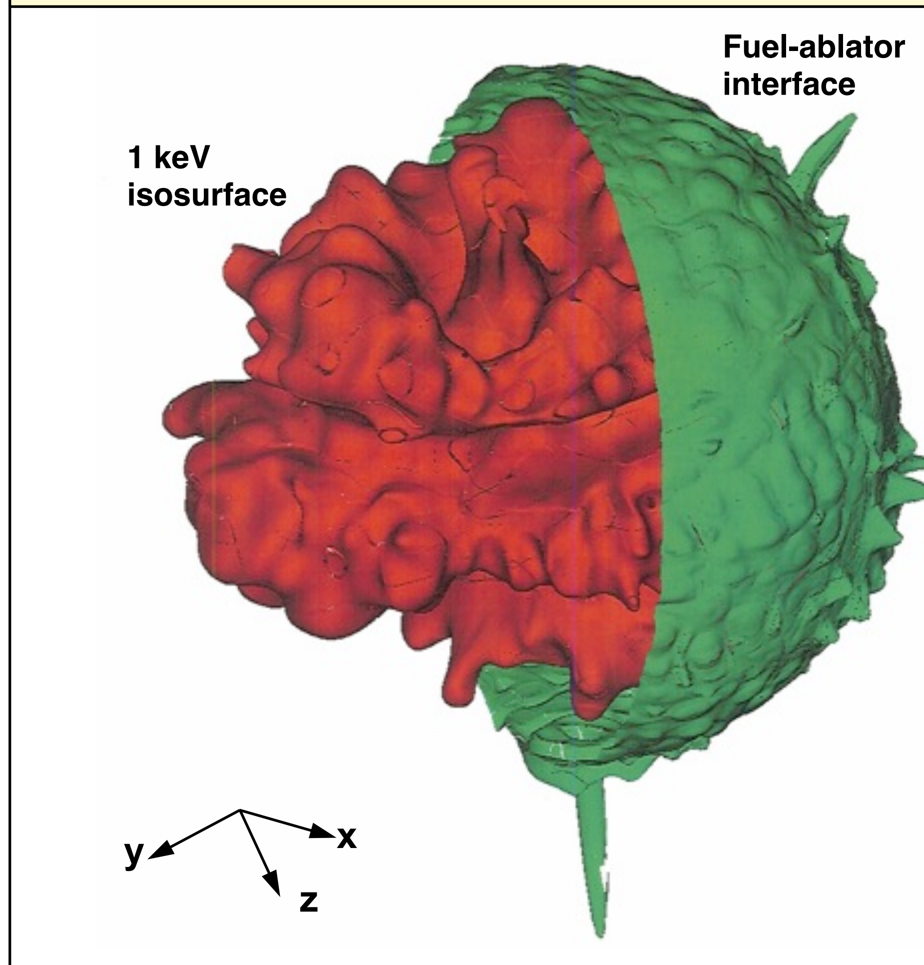
Preliminary data

2-d and 3-d capsule simulations are used to study the capsule implosion

2-D simulation at bang time
$\ell \leq 100$ resolution



3-D simulation at bang time
$\ell \leq 50$ resolution

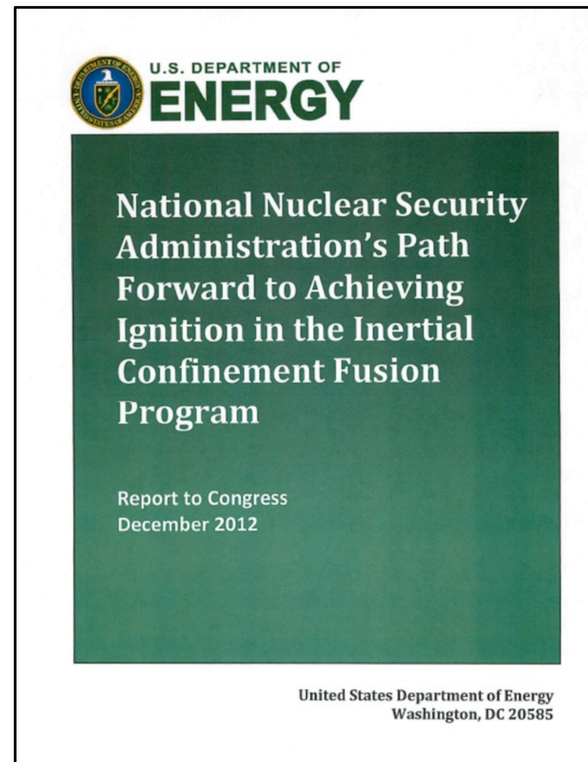


NIF laser, targets, and diagnostics are in place and significant progress has been made toward ignition

- Full-scale fusion facility is now operational, working to ignition specifications
  - Full energy, high availability laser
  - Wide diagnostics suite
  - Broad set of experimental platforms

- After 18 months of cryogenic layered, implosion experiments, now within a factor of 2-3 in pressure from ignition
  - This corresponds to a factor of 5-10 in yield

- Focus now is on understanding the remaining gap
  - Near term focus will be on the interaction of gross asymmetry with fuel mix
  - Approach outlined in NNSA report to Congress (Dec 2012)


U.S. DEPARTMENT OF
ENERGY

National Nuclear Security Administration's Path Forward to Achieving Ignition in the Inertial Confinement Fusion Program

Report to Congress
December 2012

United States Department of Energy
Washington, DC 20585


NIF