Overview of Target Fabrication at LLNL

International Nuclear Target Development Society Conference

October 9, 2018

Suhas Bhandarkar

Thanks to the NIF & Target Fabrication team

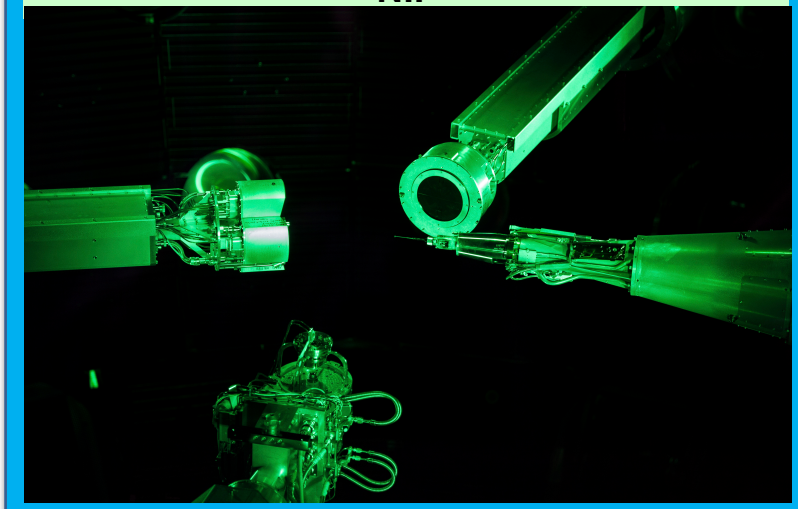
LLNL-PRES

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC

Lawrence Livermore National Laboratory

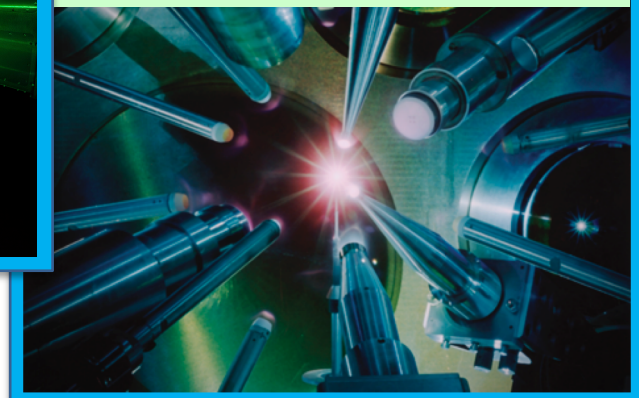
It's an exciting time in the field of High Energy Density Science at NIF, Omega and Z facilities for stockpile stewardship mission and related basic science research

NIF

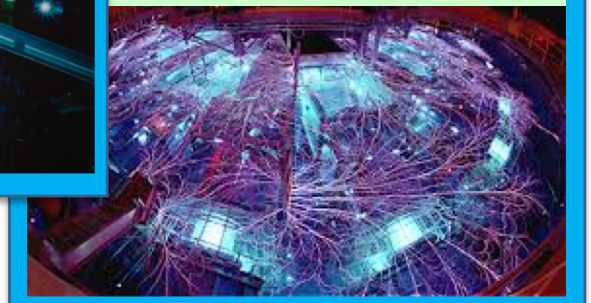


Nearly 500 NIF and over 800 Omega targets are produced per year

Omega



Z pinch

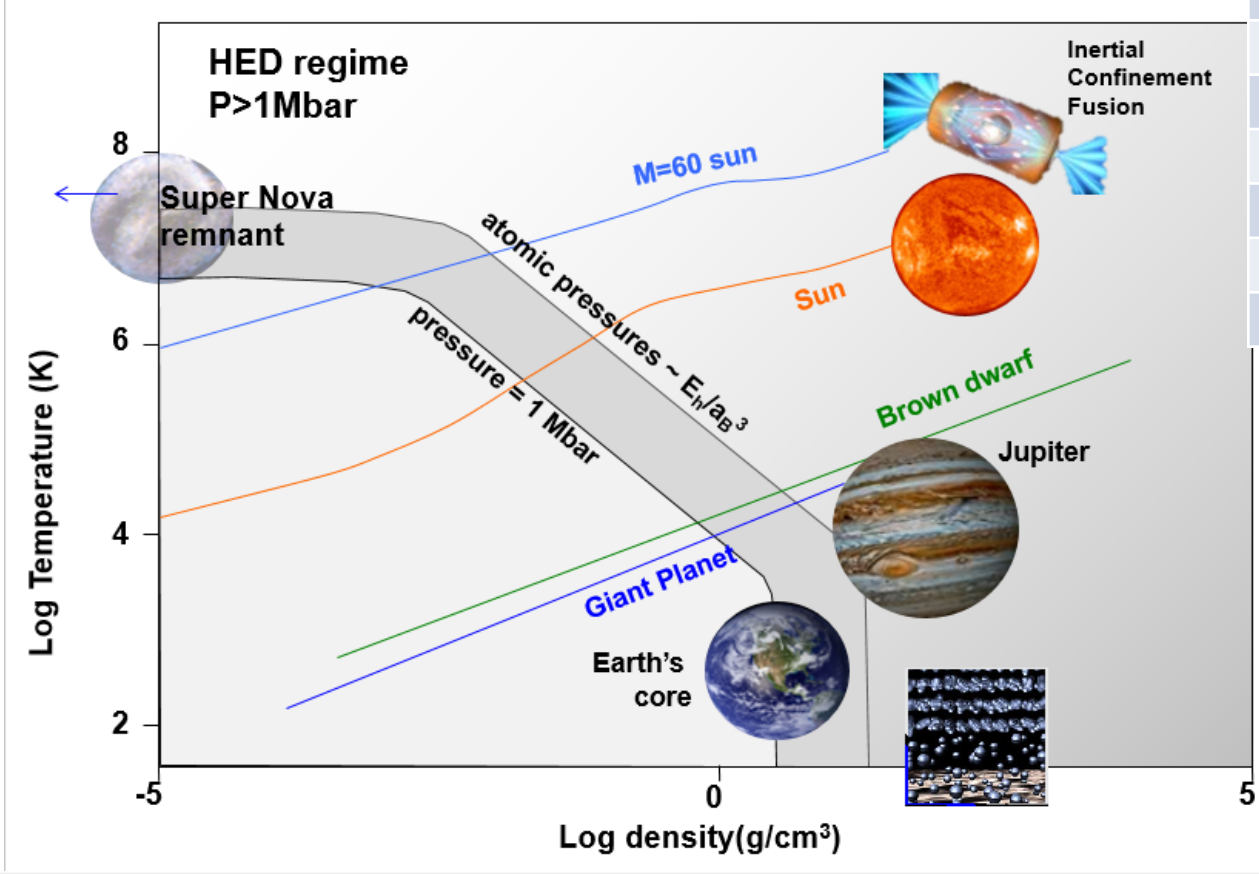


As well as smaller facilities (JLF, etc.)

Reliable target fabrication with the associated science & technology development is a critical part of this mission

Matter in High Energy Density (HED) conditions is found throughout the universe and this science is key to fusion research

HED threshold is pressures >1 Mbar: exceeds the internal energy density of molecules/atoms (solids become compressible, etc.)



Object	Pressure (Mbar)
Atmosphere at sea level	1e-6
High pressure gas cylinder	1e-4
TNT	0.1
Internal energy of H atom	1.0
Pressure at the center of Earth	3.5
Pressure at the center of Jupiter	30+
Center of the sun	$2.5*10^5$

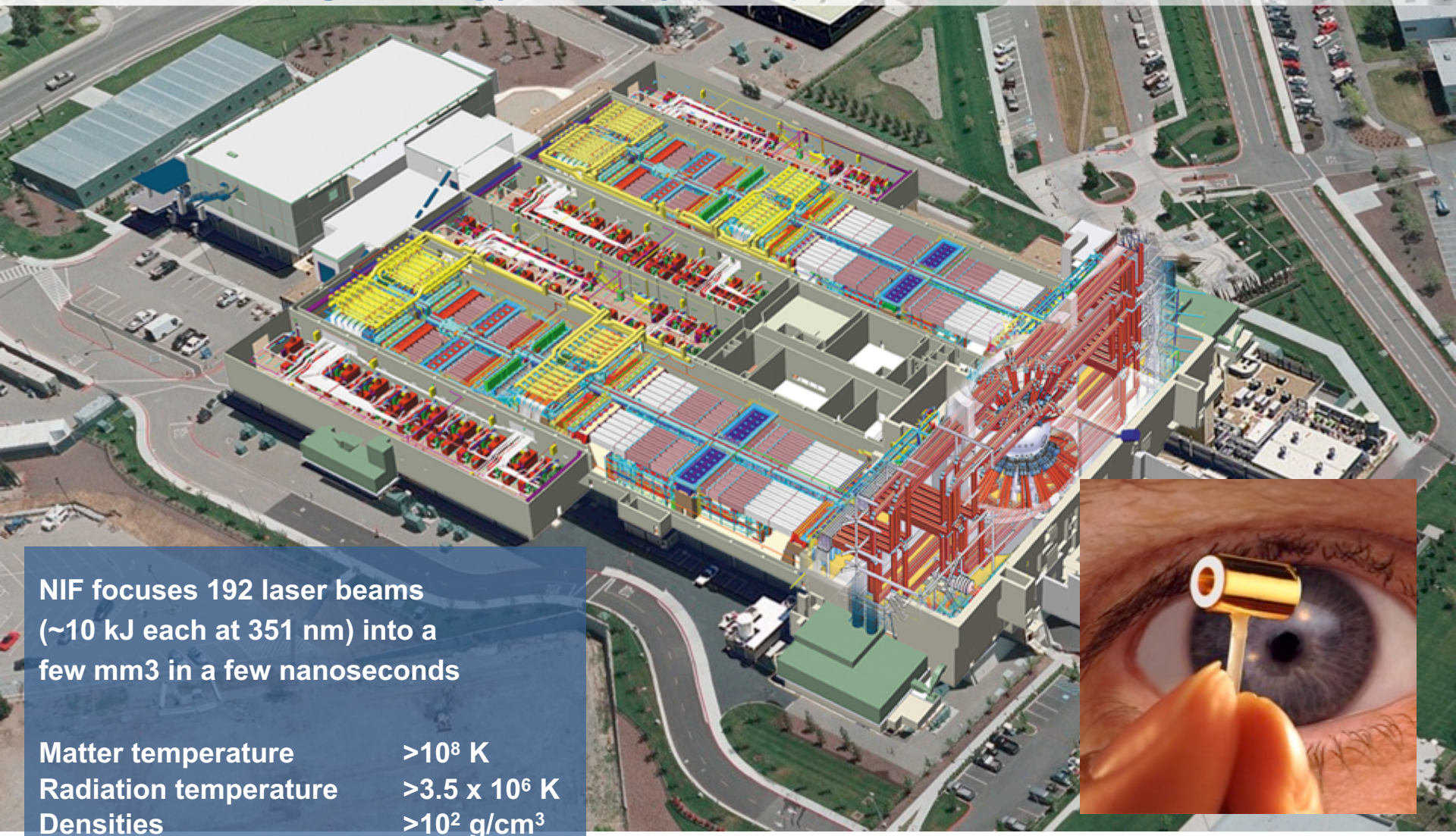
Important to understand:

Equation of State
Phase
Strength
Conductivity
Opacity
Ionization
Transport
Kinetics
Chemistry
…

The National Ignition Facility is the world's most energetic, high power laser and was designed to enable precision studies of the behavior of matter in the High Energy Density (HED) state.

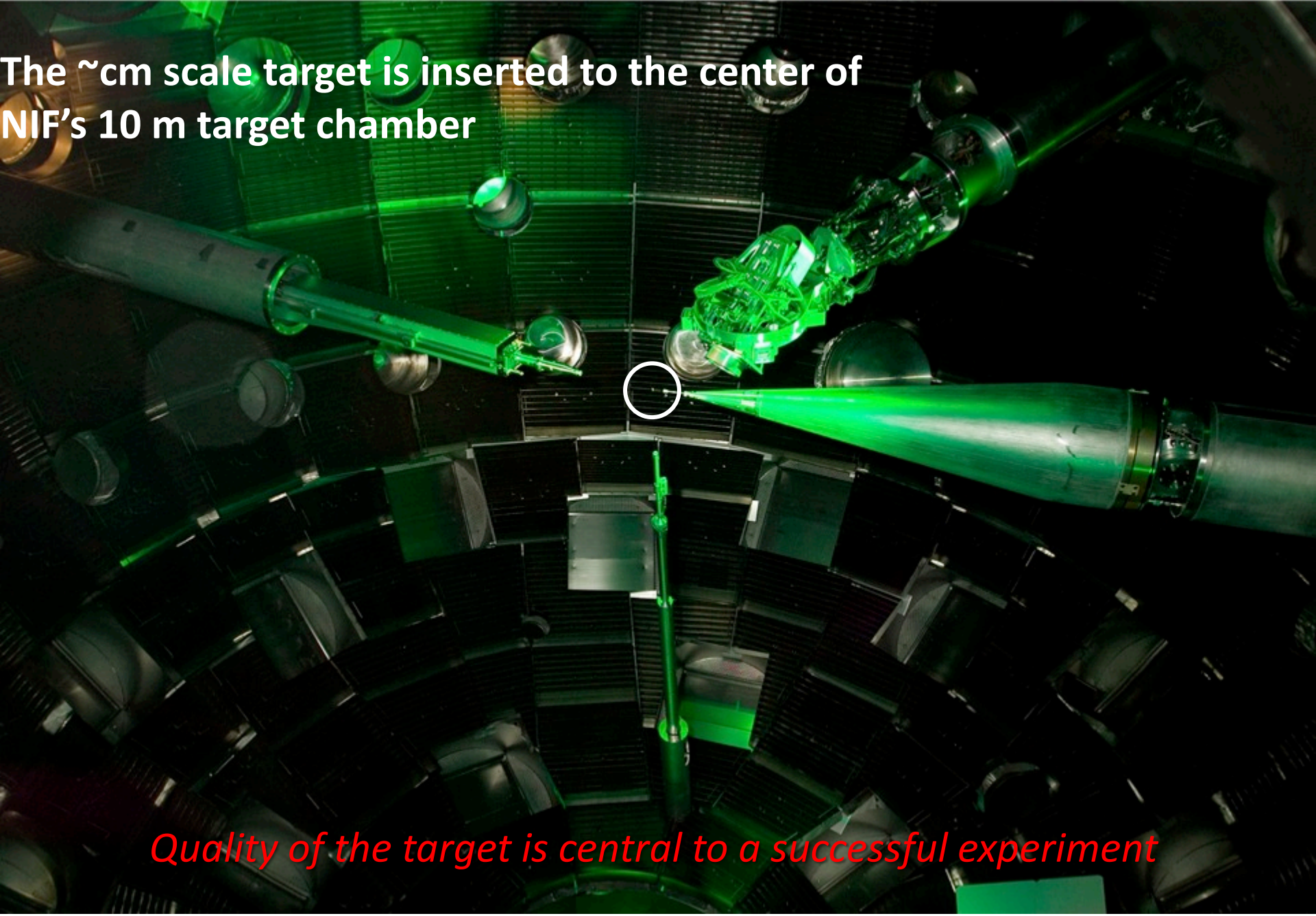
The National Ignition Facility is the world's most energetic, high power laser and was designed to enable precision studies of the behavior of matter in the High Energy Density (HED) state.

The National Ignition Facility is the world's most energetic, high power laser and was designed to enable precision studies of the behavior of matter in the High Energy Density (HED) state.



NIF focuses 192 laser beams (~10 kJ each at 351 nm) into a few mm3 in a few nanoseconds

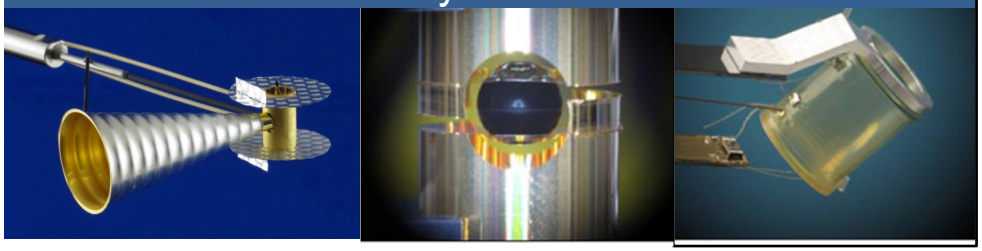
Matter temperature	$>10^8$ K
Radiation temperature	$>3.5 \times 10^6$ K
Densities	$>10^2$ g/cm^3
Pressures	$>10^{11}$ atm


The ~cm scale target is inserted to the center of NIF's 10 m target chamber
Quality of the target is central to a successful experiment

Target Fab team at LLNL designs and builds nearly 500 NIF targets per year with large number different platforms

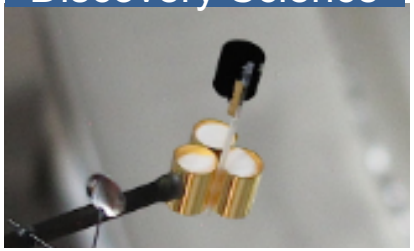
Type of targets built is determined by different stakeholders from 3 main missions

HED Physics and ICF



Nat. Sec. Apps

Discovery Science

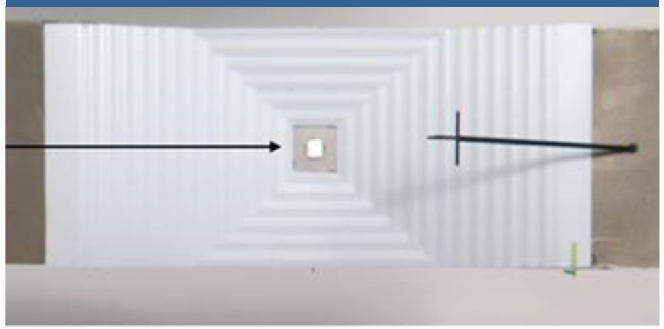


Targets we make can be grouped into 3 broad categories

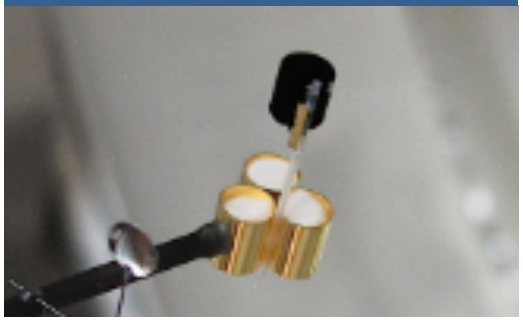
Cryogenic target

Ignition design

Complex warm (RT) target



Simple warm target



Over 200 new "models" per year

Producing NIF targets is a multi-institutional effort which require precise and timely coordination

Components & sub-assemblies ⟷ **Components & final-assemblies**

GENERAL ATOMICS

Los Alamos NATIONAL LABORATORY EST. 1943

Components and Final assembly and metrology

Multitude of vendors

Belcan

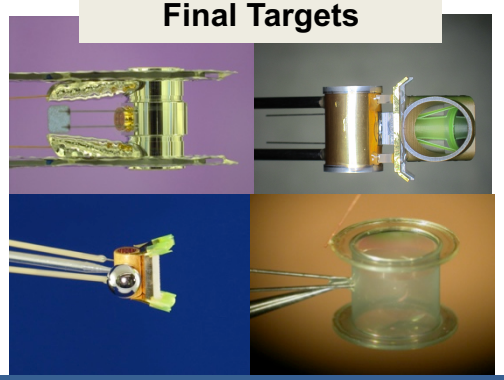
Diamond Materials
Advanced Diamond Technology

AWE

LUXEL

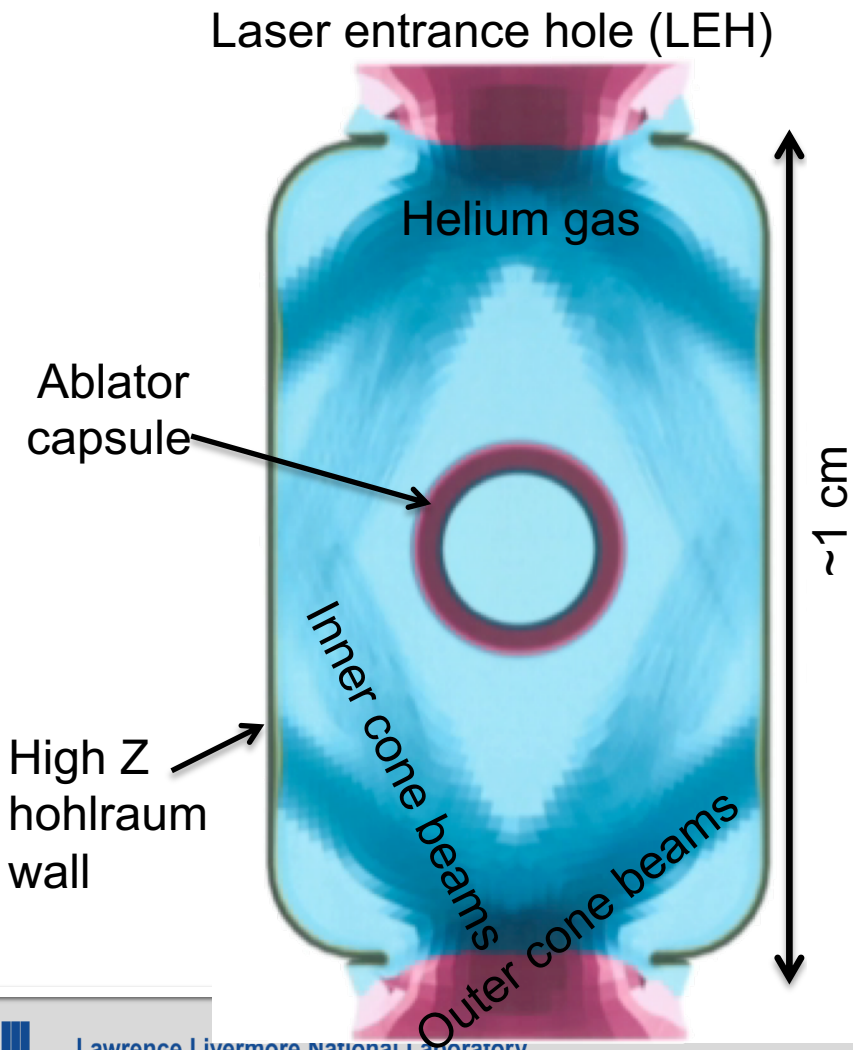
Assembled & fieldable targets

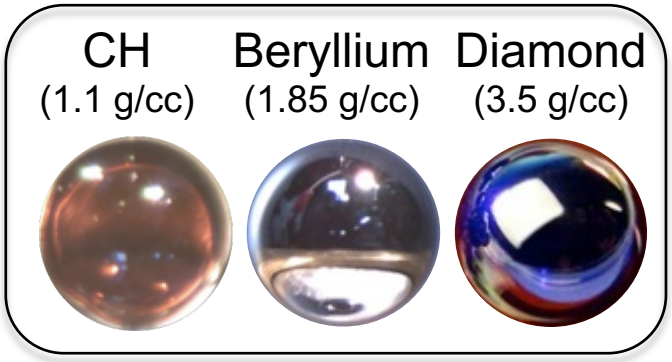
Final Targets

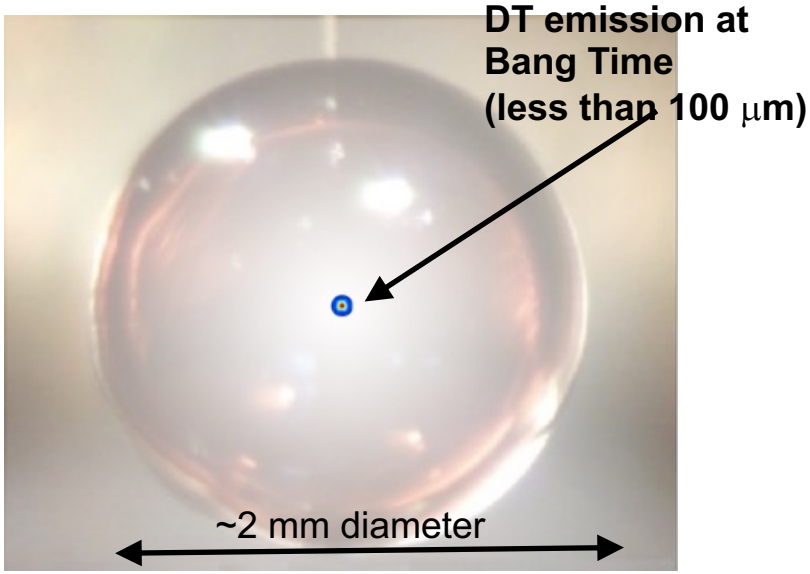


Close coordination with physics is a key part of target fab

The primary ICF approach on NIF uses the lasers to indirectly drive the capsule implosion (Laser Power→ X-ray Power)

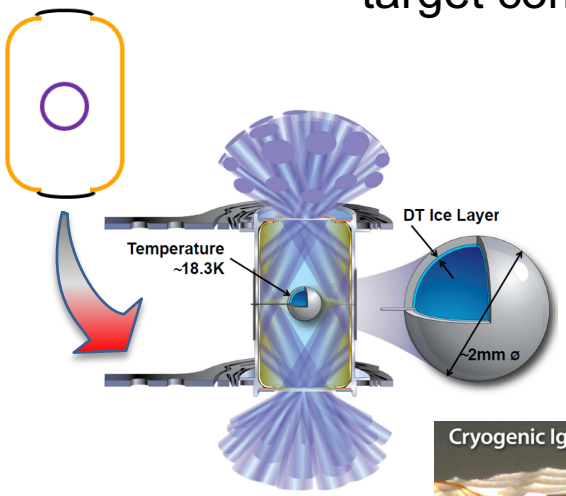


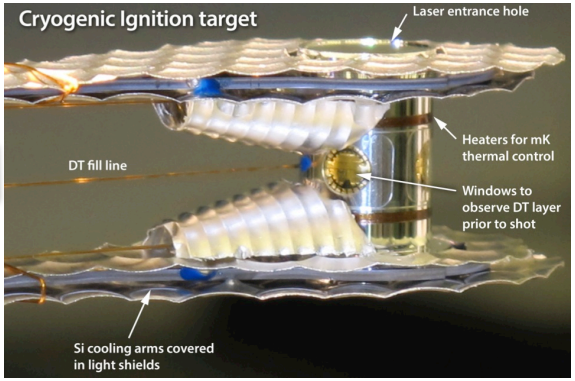


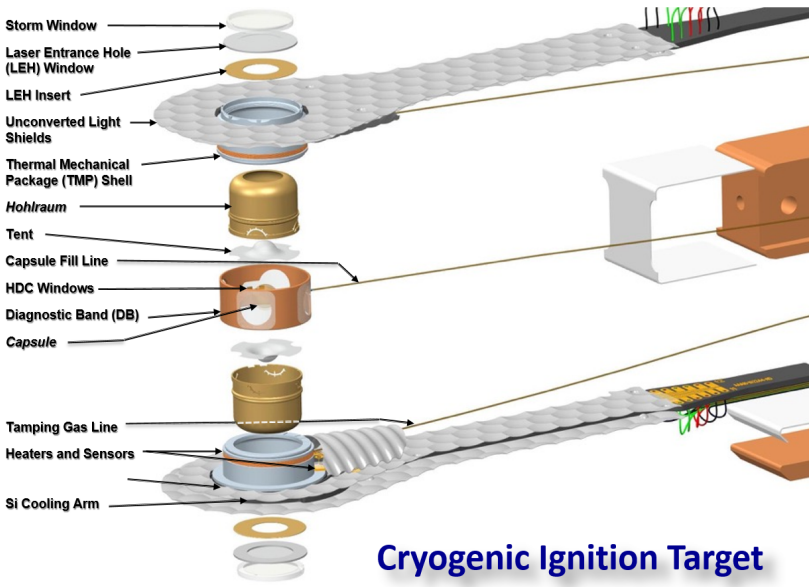


Ignition targets use a hohlraum to implode a spherical capsule with a DT payload

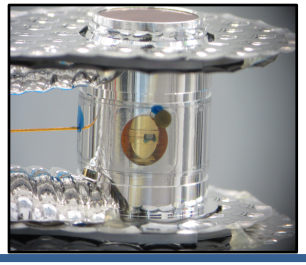
However, realization of this basic goal needs a complex target comprised of numerous of intricate components

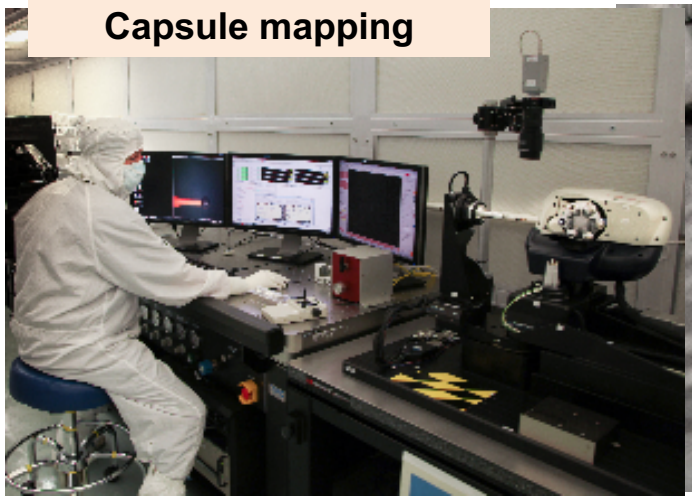


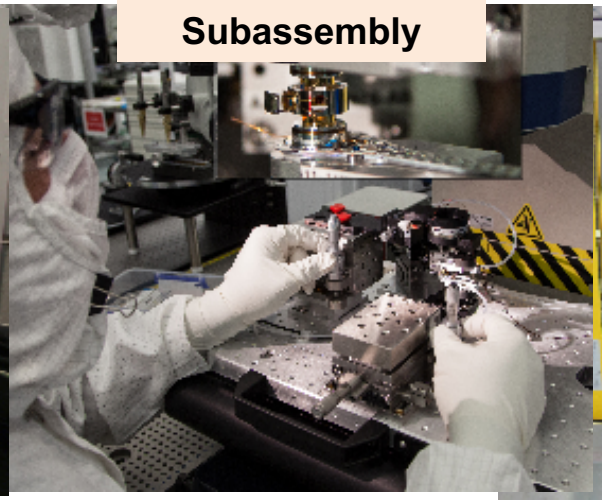


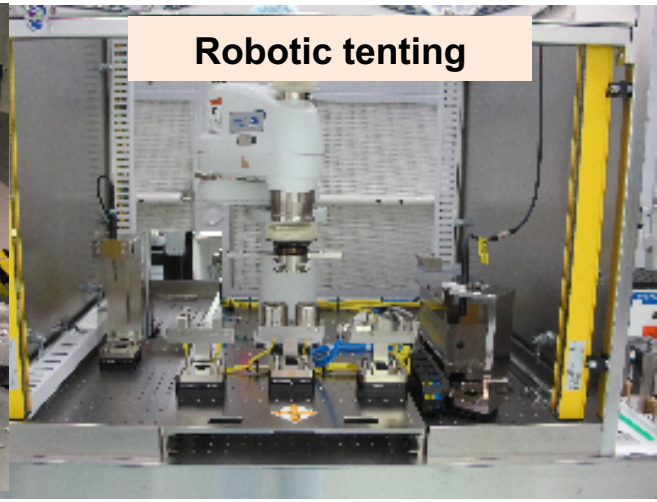


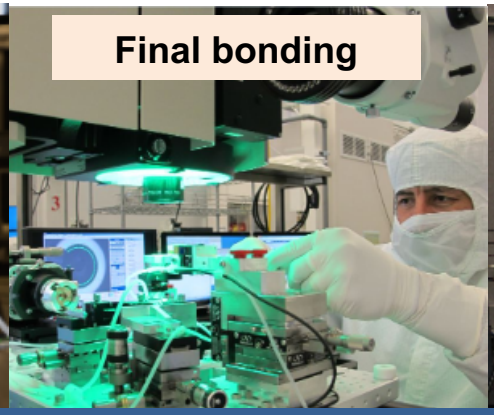
Precision assembly in cleanroom environment is coupled with in-process optical measurements to meet stringent assembly specifications







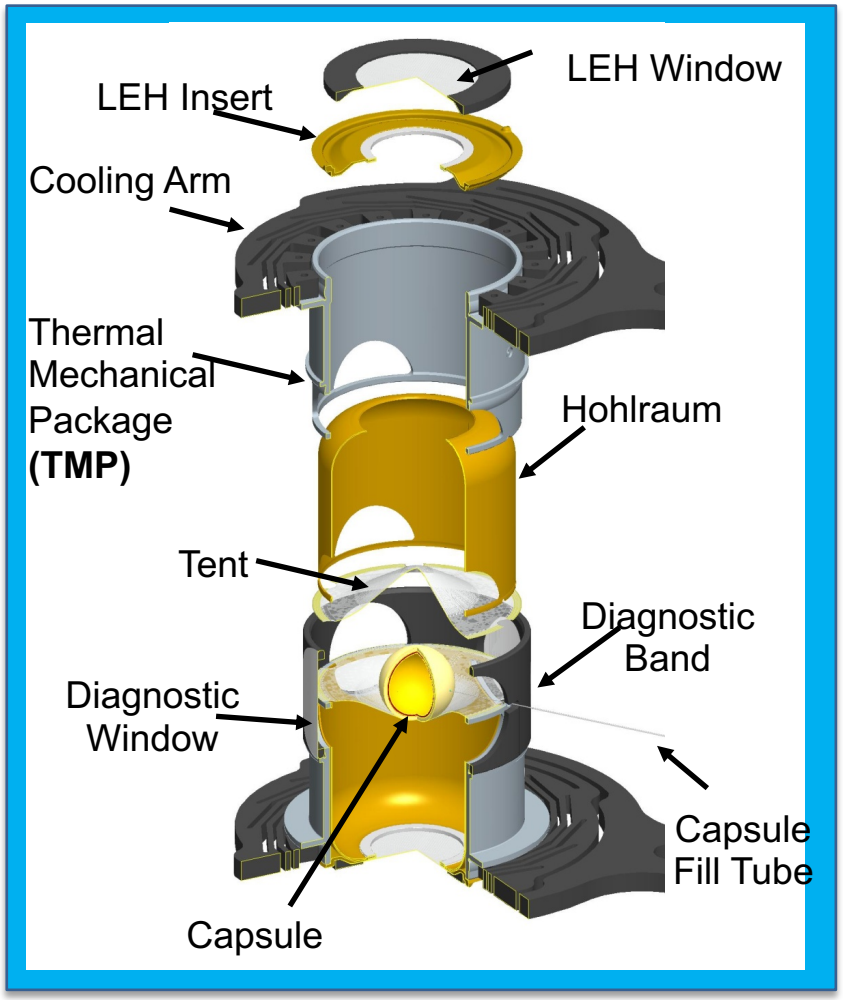


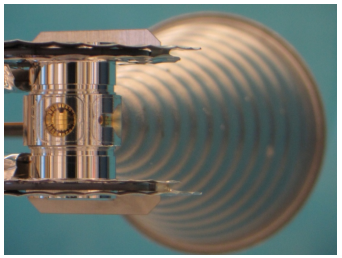


Assembly involves high value and time critical components and subassemblies requiring high yield

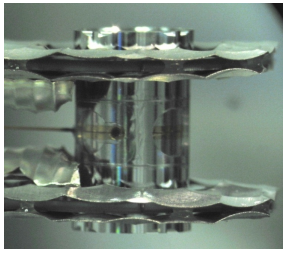
Assembly line arrangement and practices allow high throughput at required quality

Cryogenic target development has enabled studying various aspects of the implosion using a precision engineered platform

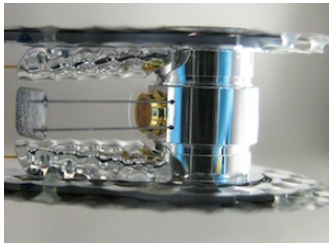




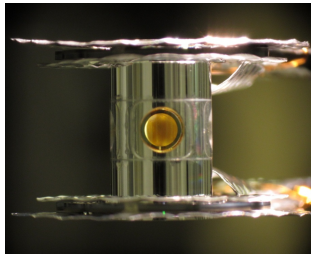
Shock timing



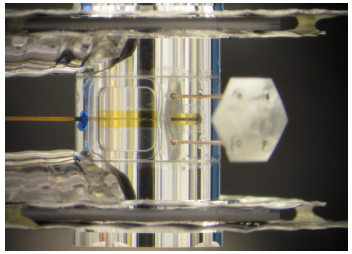
Velocity



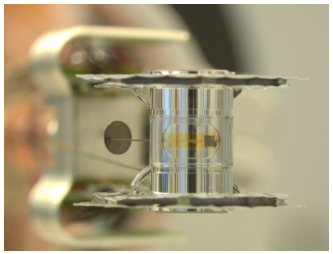
Capsule mix



2000 μm

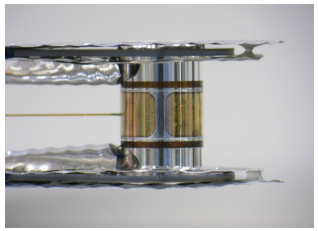


200 μm

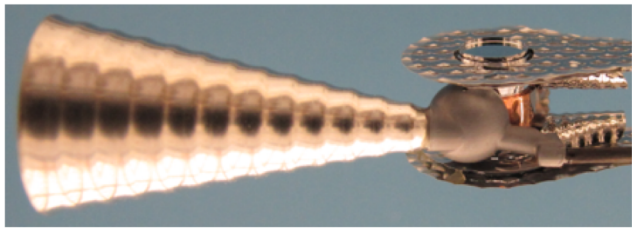


50 μm

Symmetry targets increasing CR



DT target

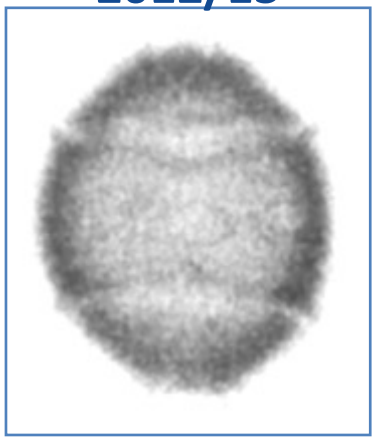


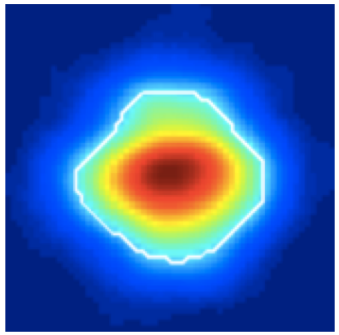
DT target with Compton radio.

From concept to design to robust production through S&T and precision engineering

At NIF, we are making progress in controlling inertial confinement fusion implosions

2012/13

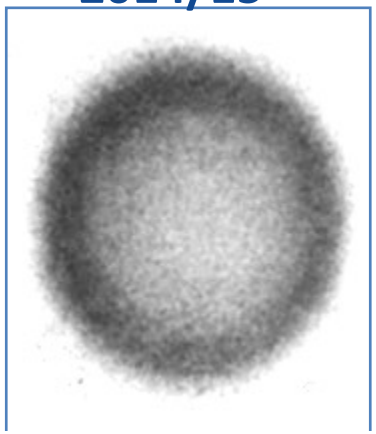


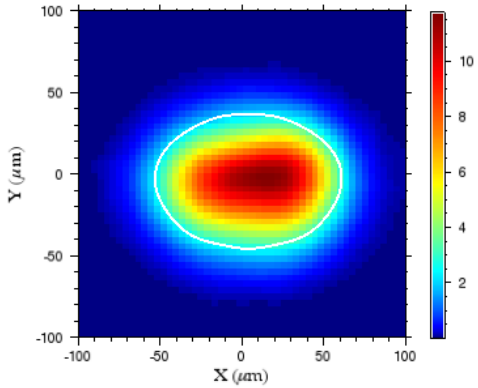


Yield ~ 2 kJ
Pressure ~ 150 GB
(7e14 DT neutrons)

Better hydro

2014/15

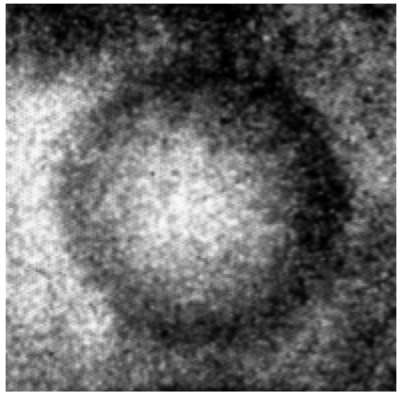


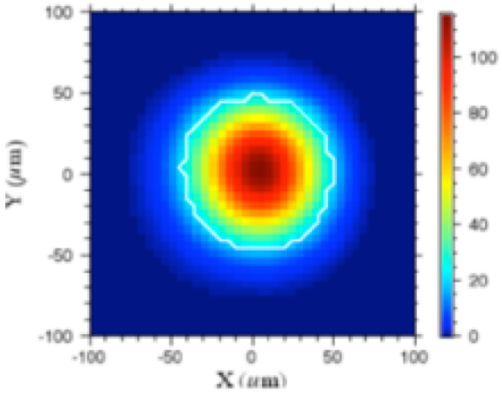


Yield ~ 27 kJ
Pressure ~ 250 GB
(9 e15 DT neutrons)

Better LPI, symmetry
Reduce fill tube

2017/18

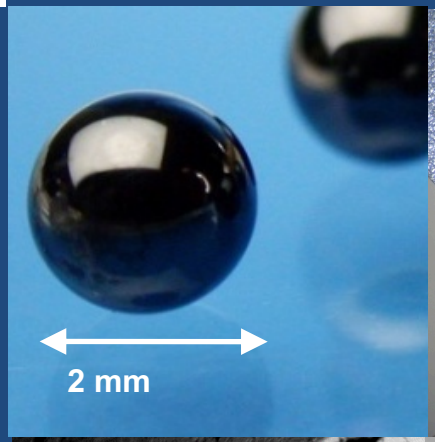
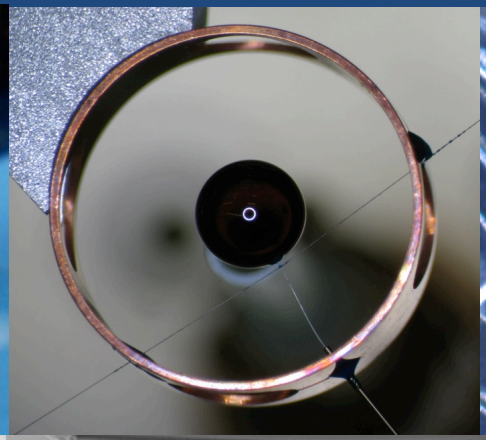
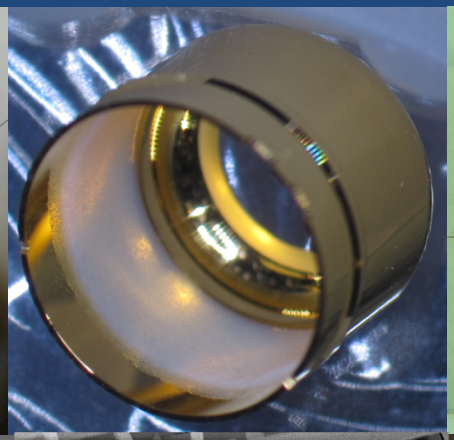
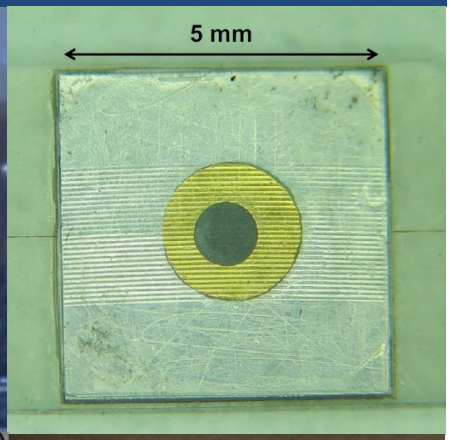
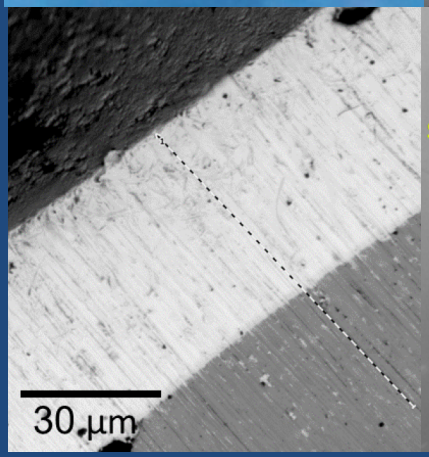
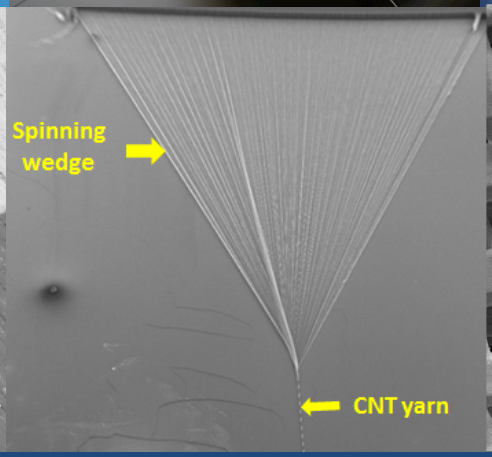
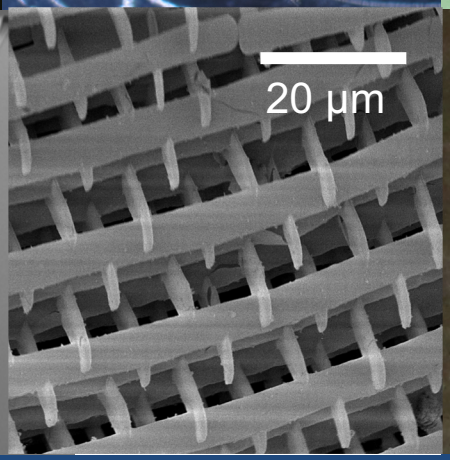




Yield ~ 57 kJ
Pressure ~ 350 GB
(2 e16 DT neutrons)

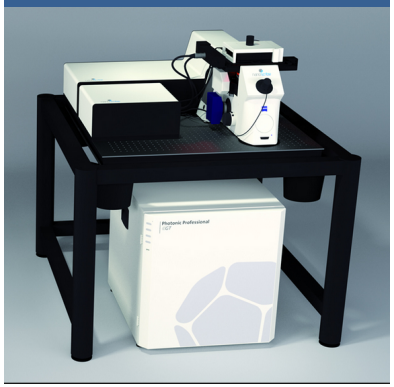
Continued improvements in target design & materials are ongoing to achieve higher yield

Basic S&T is critical in development of the complex components required to drive physics ideas forward

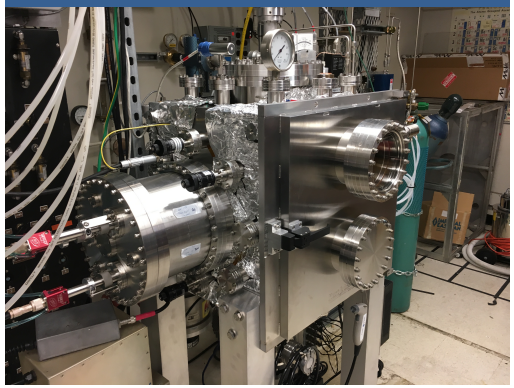
	Capsules	Capsule support	Hohlraums	Physics Packages
Components				
Materials & Methods				
	Coatings	Advanced materials	Foams	Plutonium

Targets S&T and Engineering is critical to continuously enable new classes of targets that push boundaries of precision, size & functionality

Additive Mfg

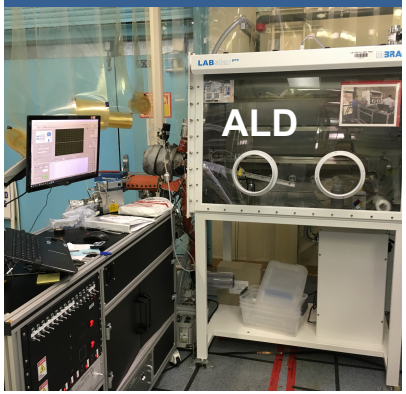


RF sputtering



E-beam coater

Atomic layer Dep.



Accelerator

TEM

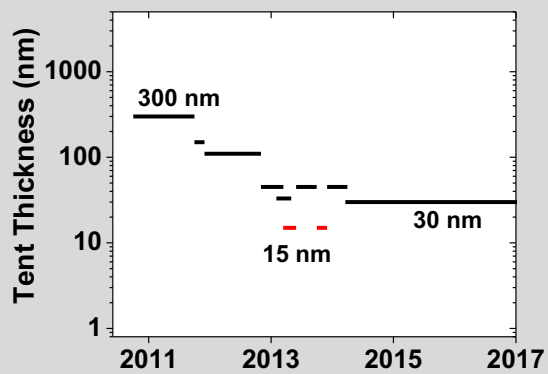
FIB

X-ray tomography

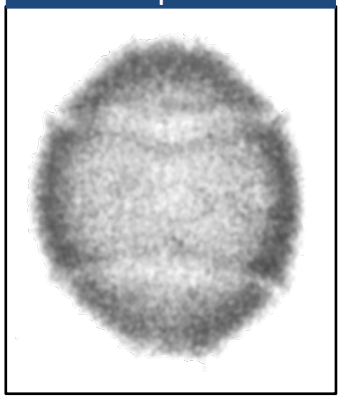
Leverages a large number of LLNL production and characterization capabilities

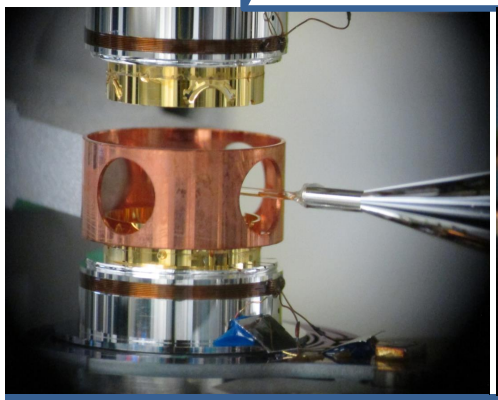
Improved capsule support: from ultra-thin films to fibers driven by physics results

Tent thickness vs time

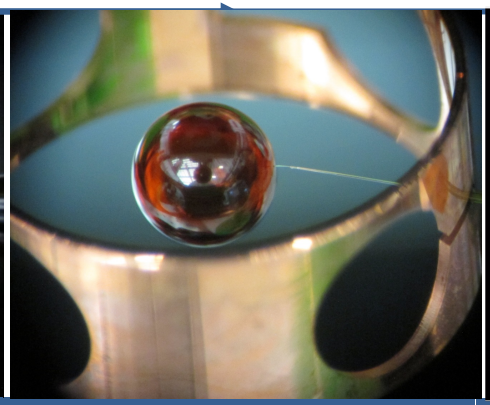


Radiograph tent impact

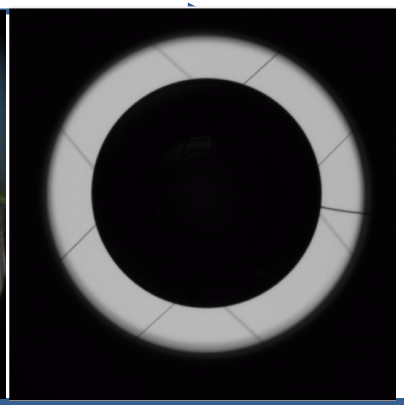




4-part hohlraum



Fishing pole



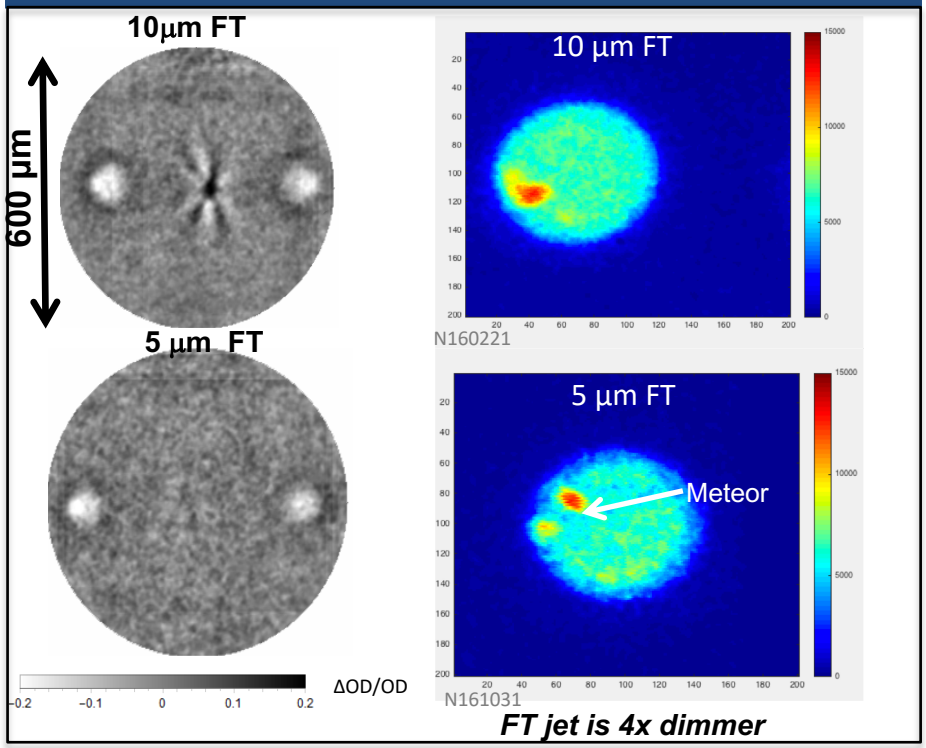
Tetracage

Magnetic levitation

Novel schemes to mitigate the defect created by the membranes used to 'tent' the capsule

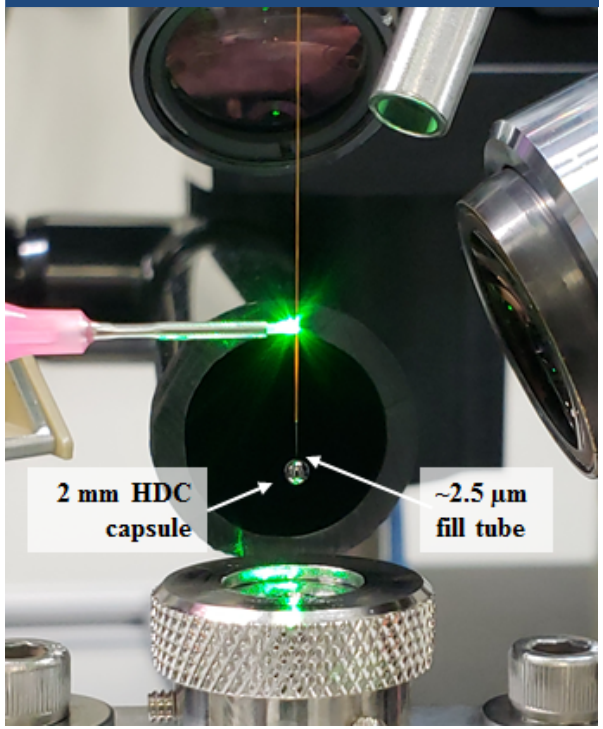
Smaller Fill tube (FT): reduces shadows cast by outer beams seeds capsule perturbation growth

Shot data on FT effects on implosion

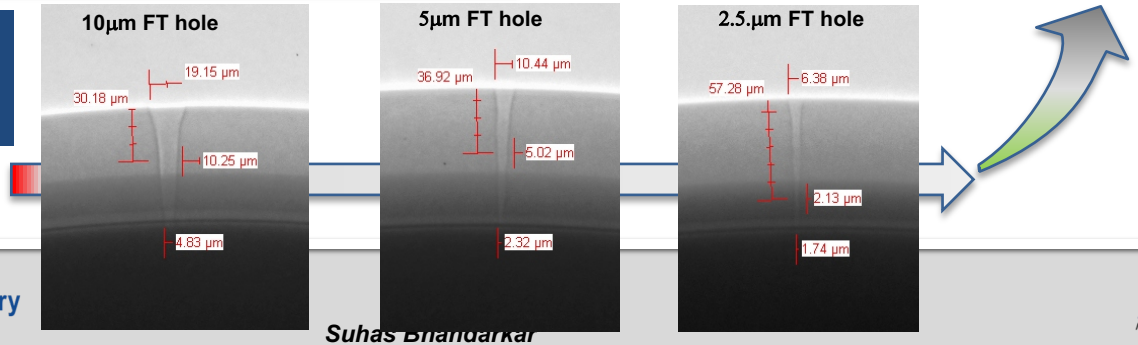


FT jet is 4x dimmer

2.5um FT target in assembly



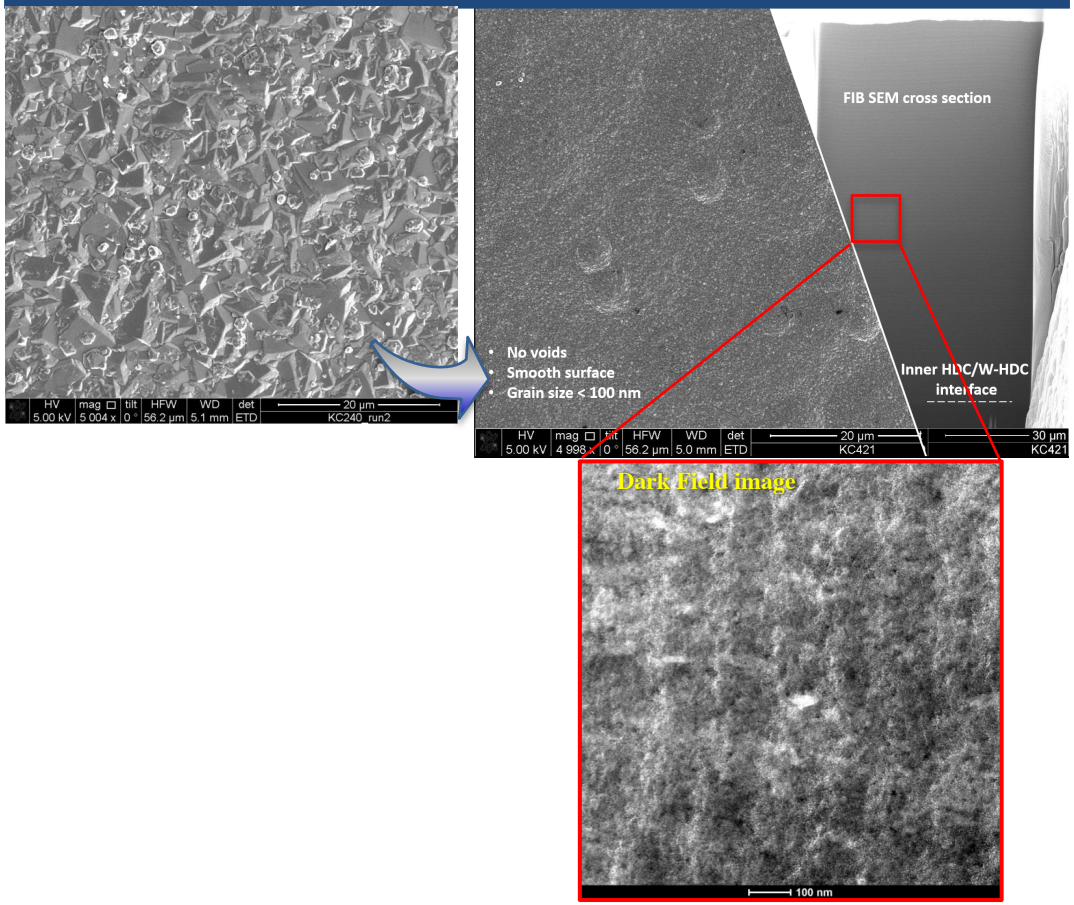
We are pushing the limits of drill-hole and FT size



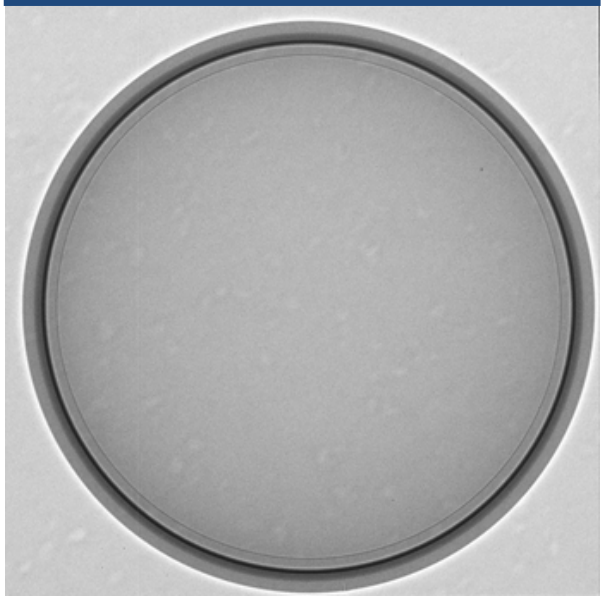
Suhas Bhandarkar

Improved ablators: Fabrication of W-doped ultra-nano-crystalline diamond (UNCD-HDC) capsules

Electron micrographs of HDC capsules with nano-grains compared to older microcrystalline structure



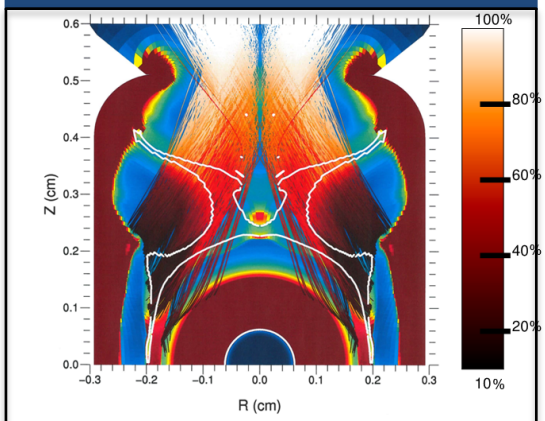
W doped HDC capsule with DT ice layer before shot

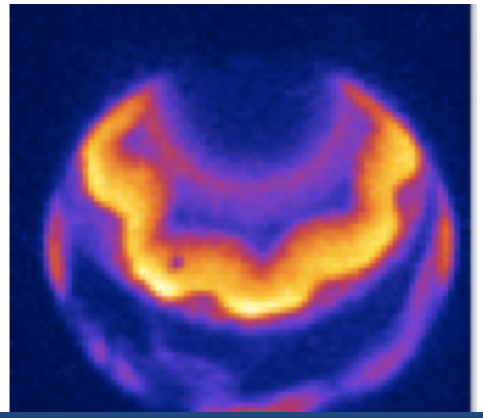


This advance allows greater structural homogeneity within the ablator wall

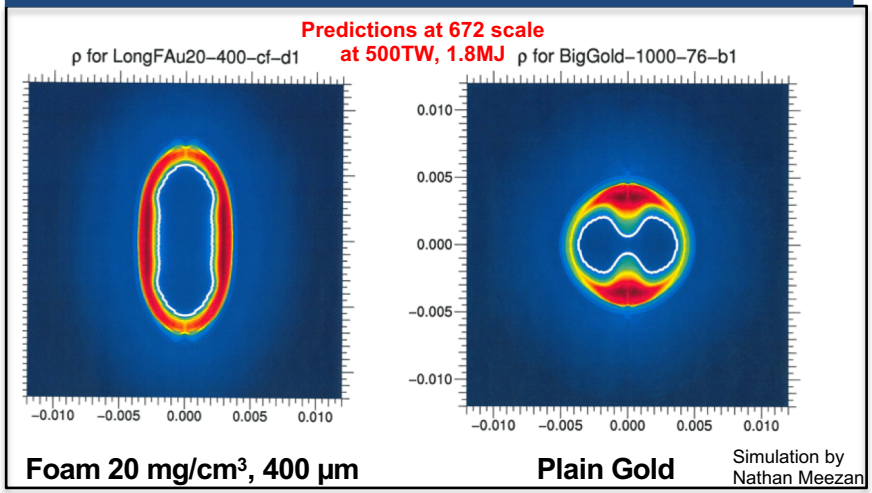
Improved hohlraums: New designs and low density foam to control hohlraum wall-motion

Hohlraum wall motion: simulations & data

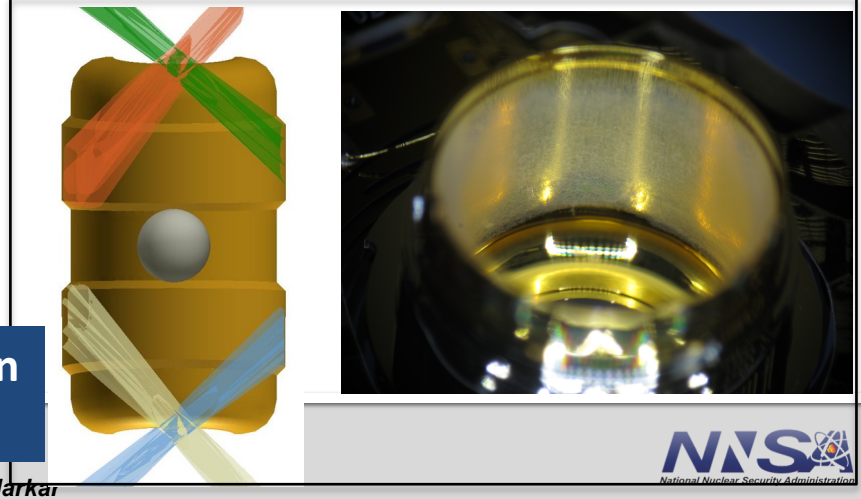




Simulation of shape control using foam



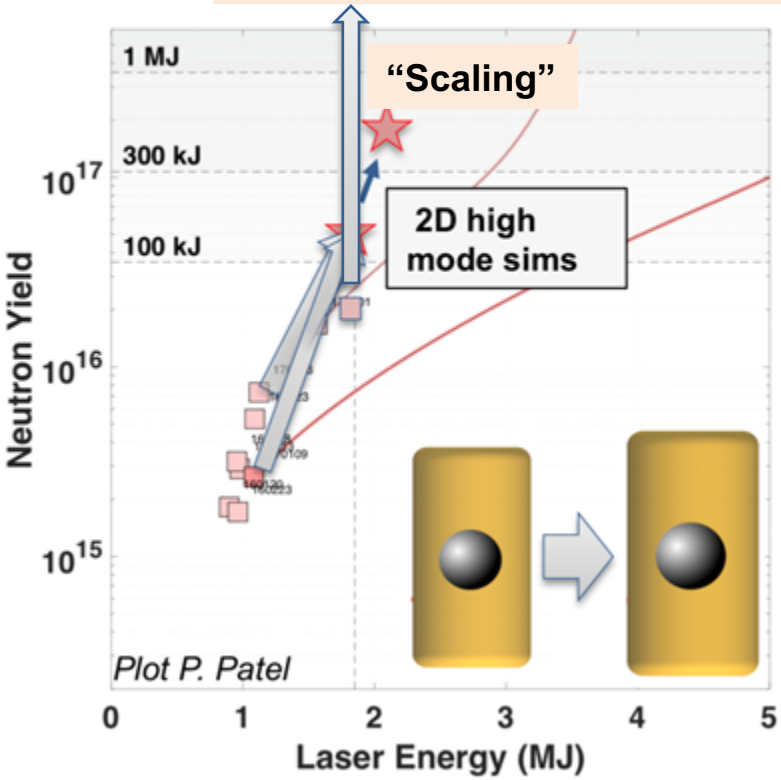
Mitigation: Iraum & foam lined hohlraum



Allows better control of inner beam propagation and affects shape of the implosion

The next big step for the ICF Program is to try and maximize implosion scale & coupled energy

"Quality" : better capsule support, ablators & hohlraums and smaller tubes



Our plan is to improve the quality of the implosion and amount of energy coupled to the capsule via

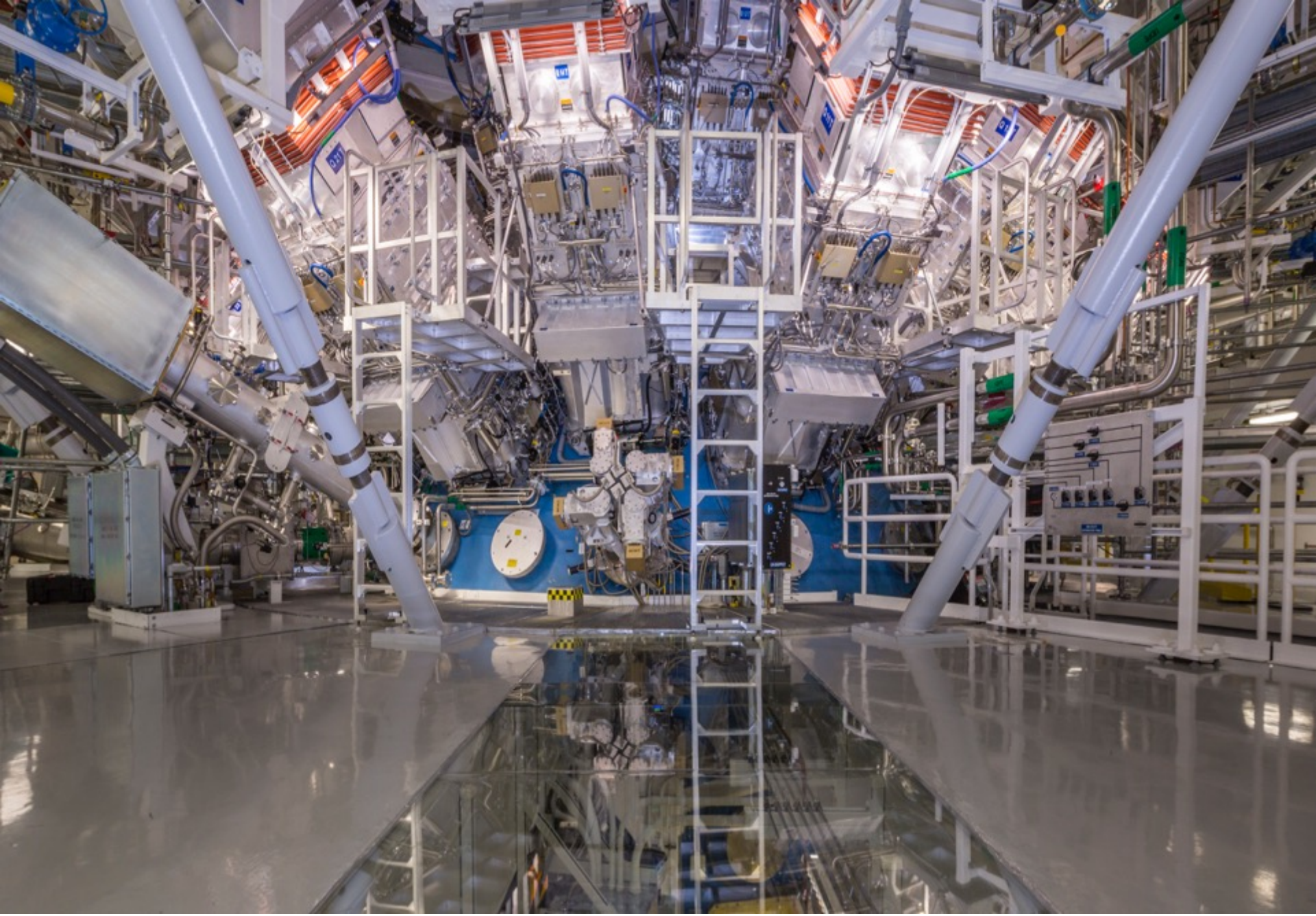
- **Smaller fill tube**
- **Improve capsule support**
- **Improved hohlraums to allow larger capsules**
- **Improved ablator materials**

Improved quality of implosion including target fabrication advances can have a dramatic impact on performance

Target fab improvements are critical in improving quality of implosions to allow higher yield at available NIF energies

Close coupling of Target Fabrication with ICF/HED physics community is key in making advances on the National Ignition Facility

- **Many stakeholder groups weigh in on the types of targets that are being built and review the target design for compatibility with facility, diagnostics, layering, etc.**
- **Science and technology are essential elements for Target Fabrication that allow us to push the boundary on what experiments can be performed.**
- **On NIF we are performing ~ 2 experiments per day studying some of the most fundamental questions facing the field of high energy density science**
- **Achieving inertial confinement fusion ignition in the Laboratory is a grand scientific challenge.**
- **Progress is being made on understanding and improving inertial confinement fusion target performance, driven by new measurements.**
- **We remain committed to the exciting goal of obtaining fusion ignition in the laboratory**



Lawrence Livermore
National Laboratory