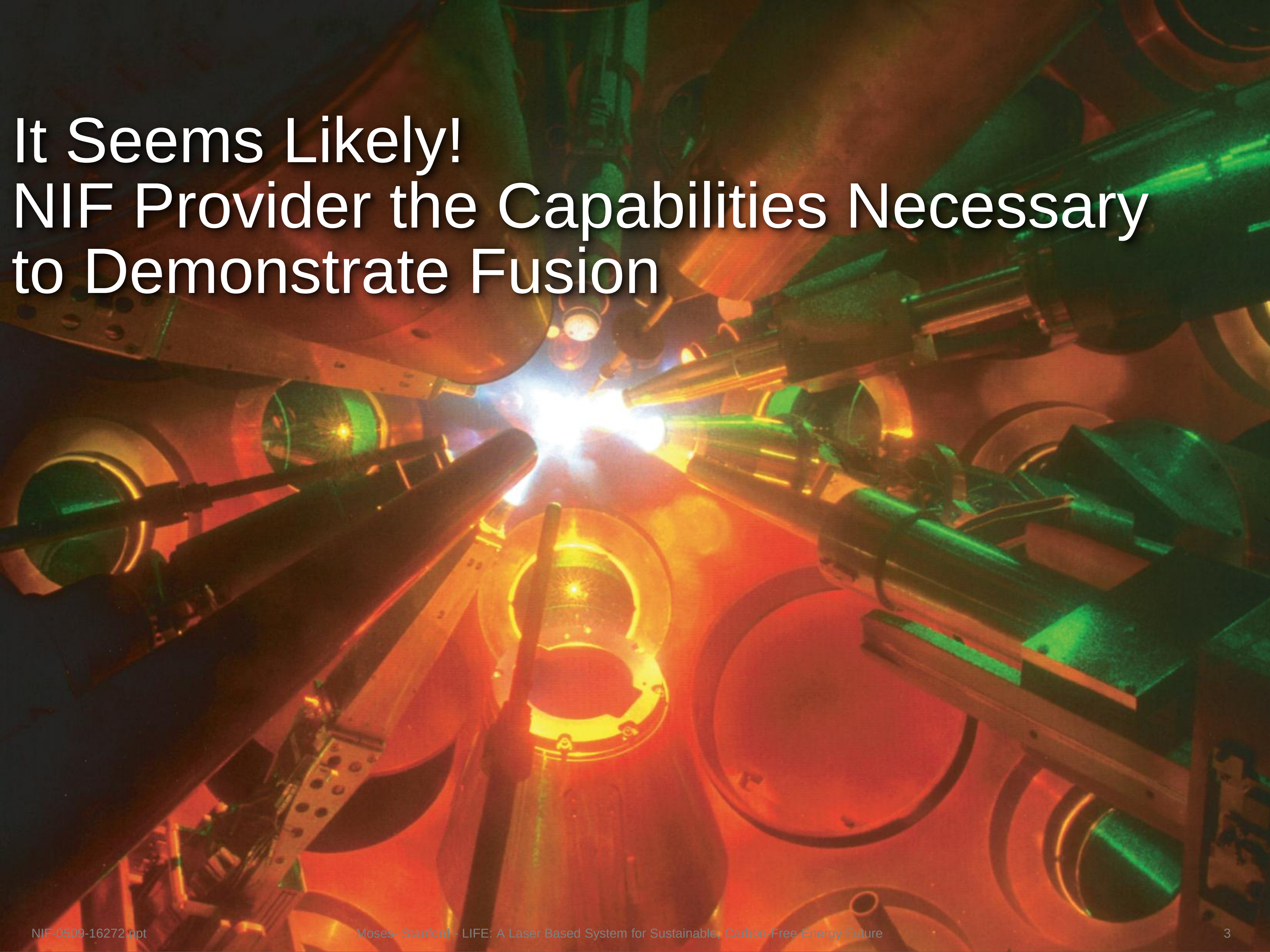
The National Ignition Facility:
Exploring Matter Under Extreme Conditions

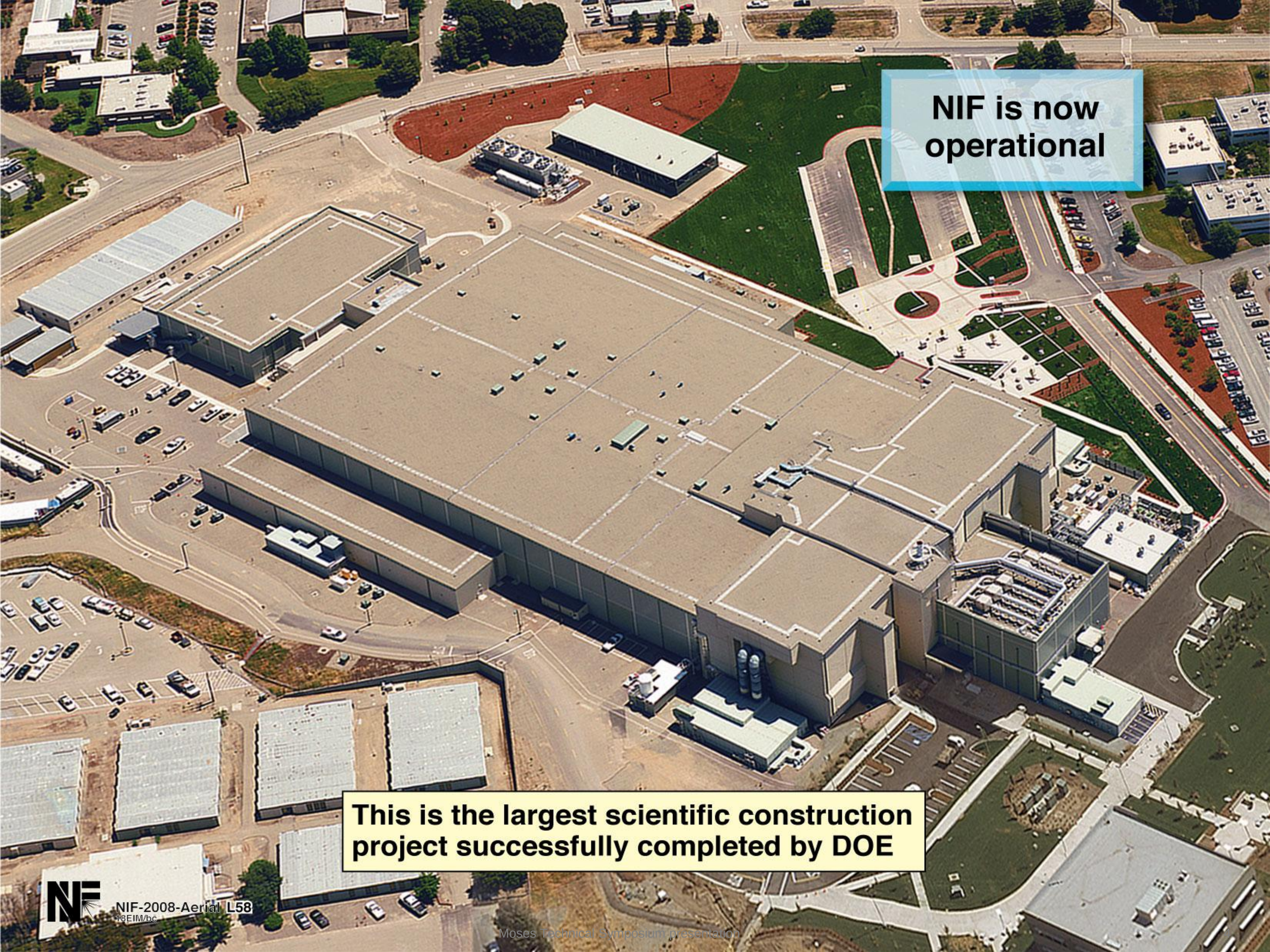
Edward I. Moses
Principal Associate Director, NIF & PS
Presented to: Plenary Talk Conference on Lasers and Electro-Optics (CLEO) and the International Quantum Electronics Conference (IQEC)

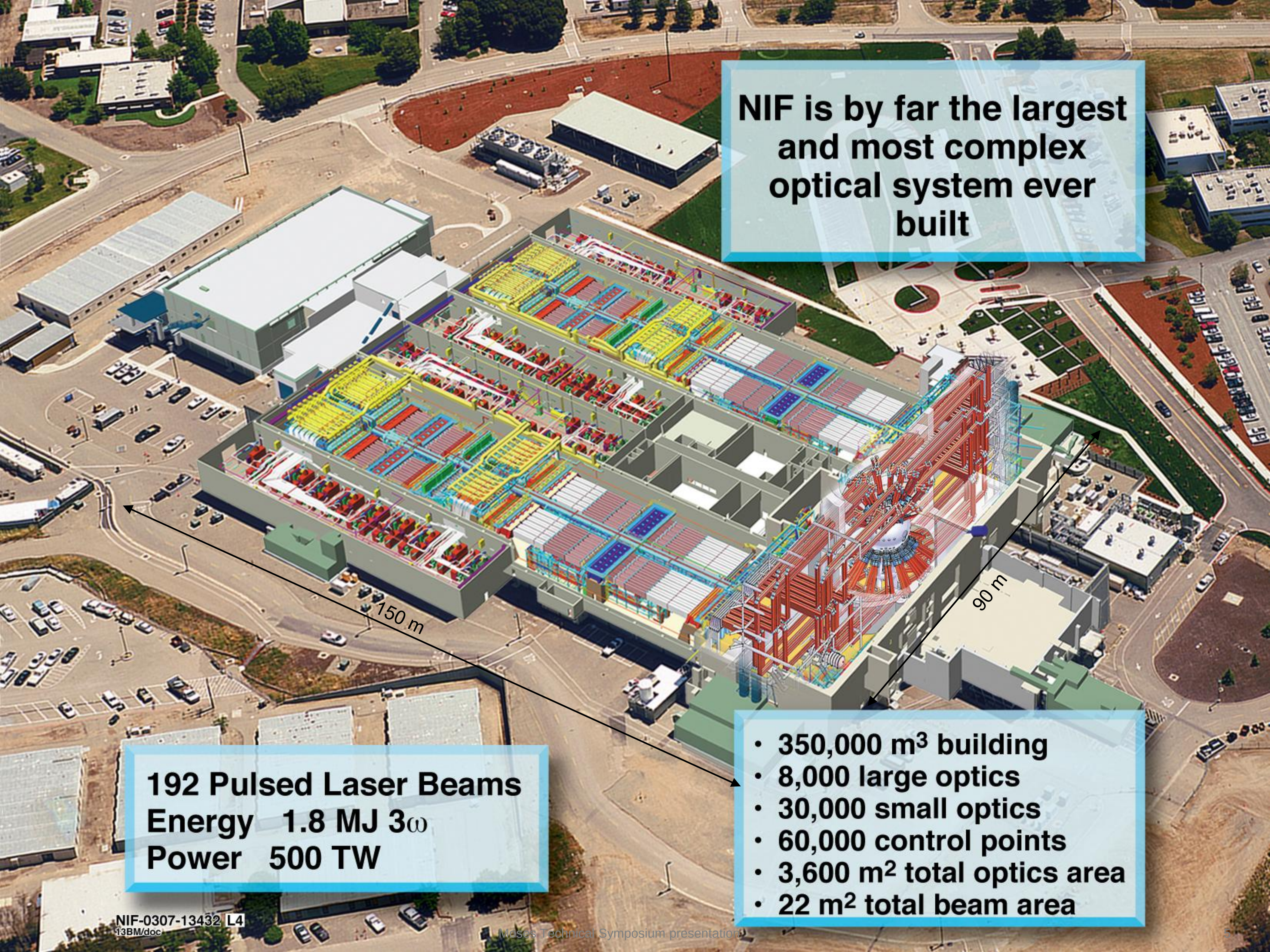
This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344

Could We Build a Miniature Sun on Earth?

It Seems Likely!
NIF Provider the Capabilities Necessary to Demonstrate Fusion




NIF is now operational
This is the largest scientific construction project successfully completed by DOE


NIF is by far the largest and most complex optical system ever built
150 m
90 m
192 Pulsed Laser Beams
Energy 1.8 MJ 3ω
Power 500 TW
• 350,000 m3 building
• 8,000 large optics
• 30,000 small optics
• 60,000 control points
• 3,600 m2 total optics area
• 22 m2 total beam area
NIF-0307-13432 L4
13BM/doc
Moses Technical Symposium presentation

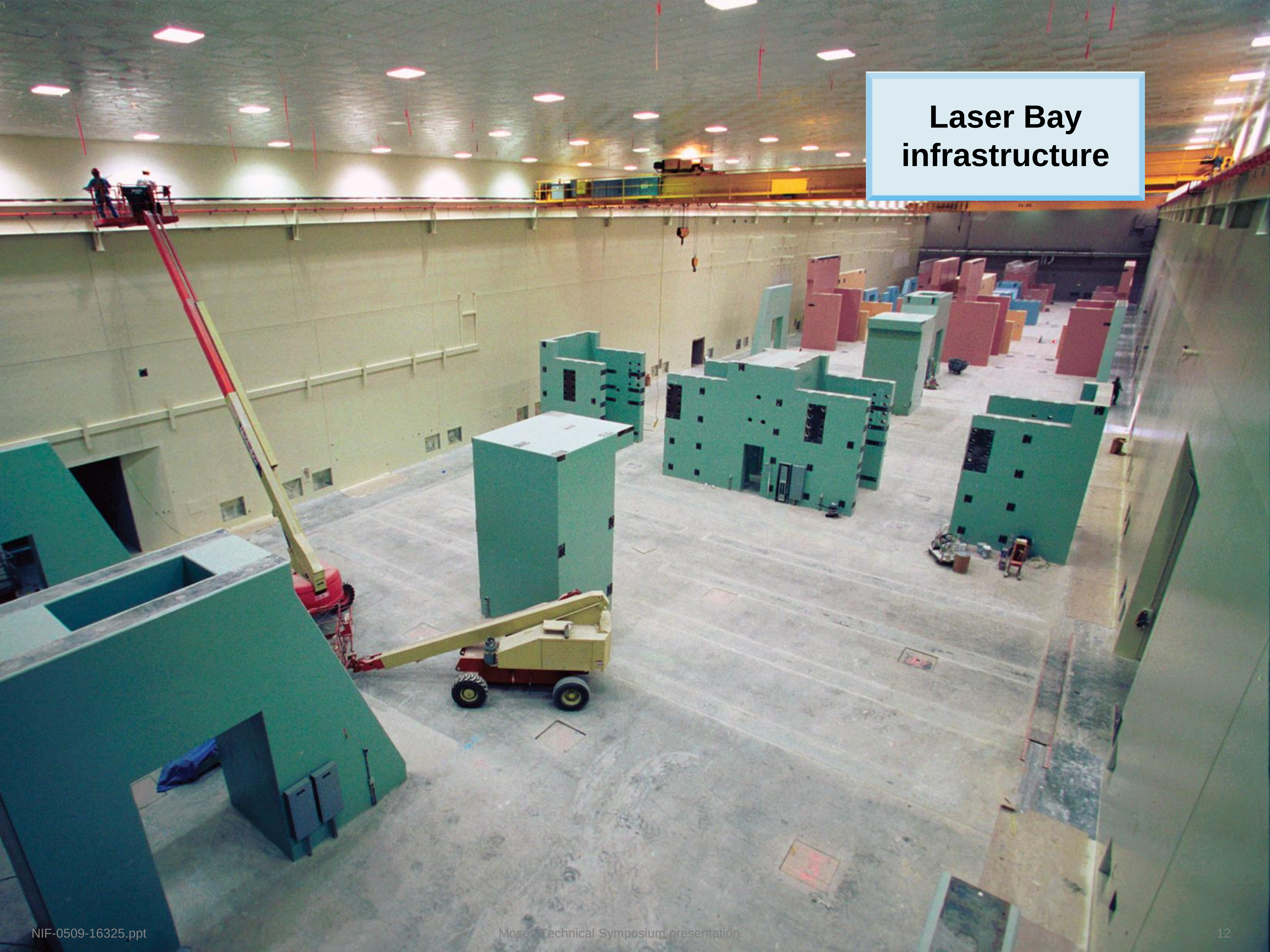

NIF will be begin the full physics ignition experimental campaign in 2010
• 192 Beams delivered to Target Chamber Center
1.1 MJ March 10, 2009
NIF-0409-16244


Building NIF has been a challenging and exciting journey
NIF’s Conceptual Design Report was issued in March, 1994
NIF-0509-16312r1-lay1

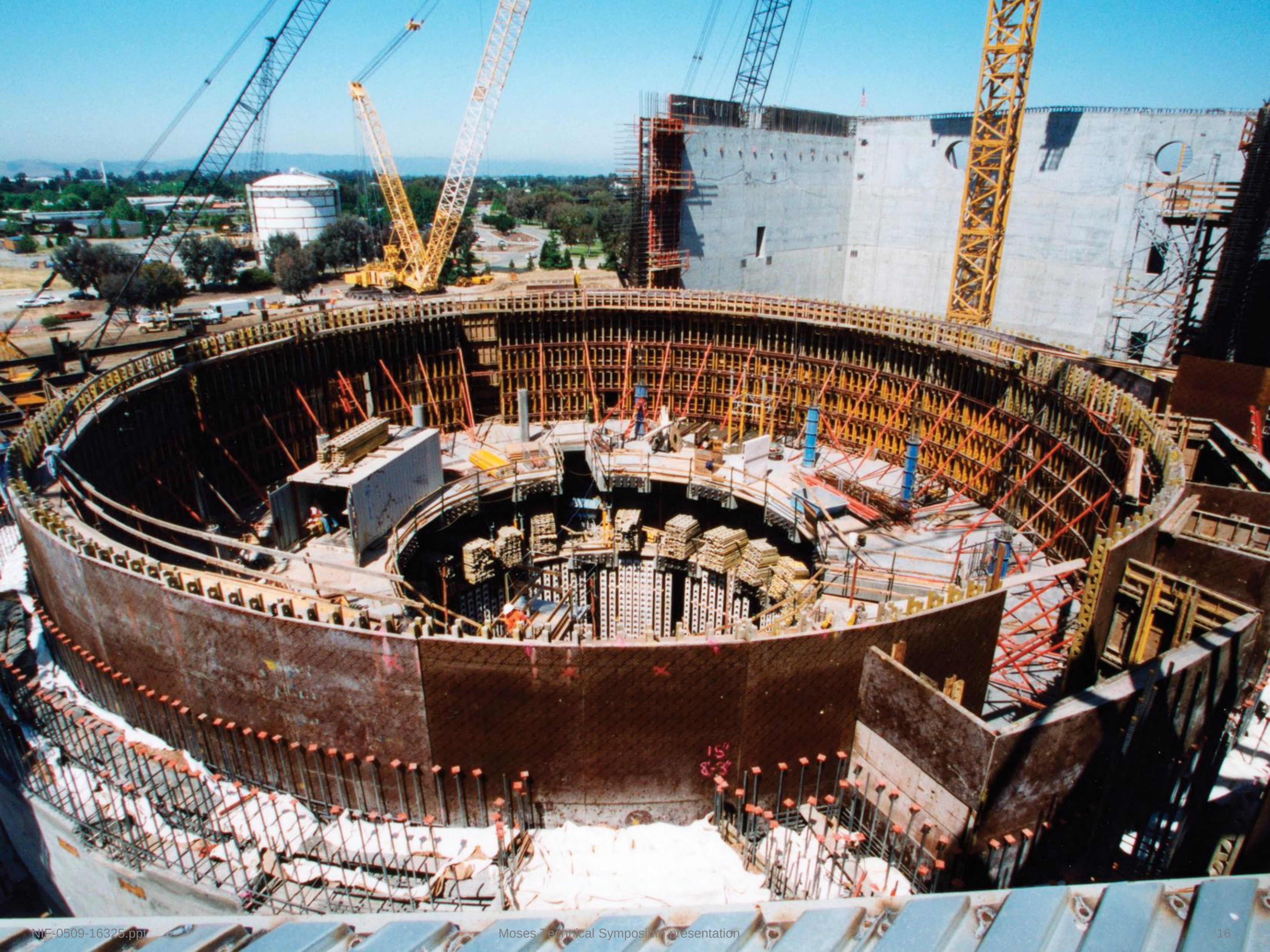
NIF Groundbreaking May 1997


NIF Operational
March 2009
NIF-0509-16336

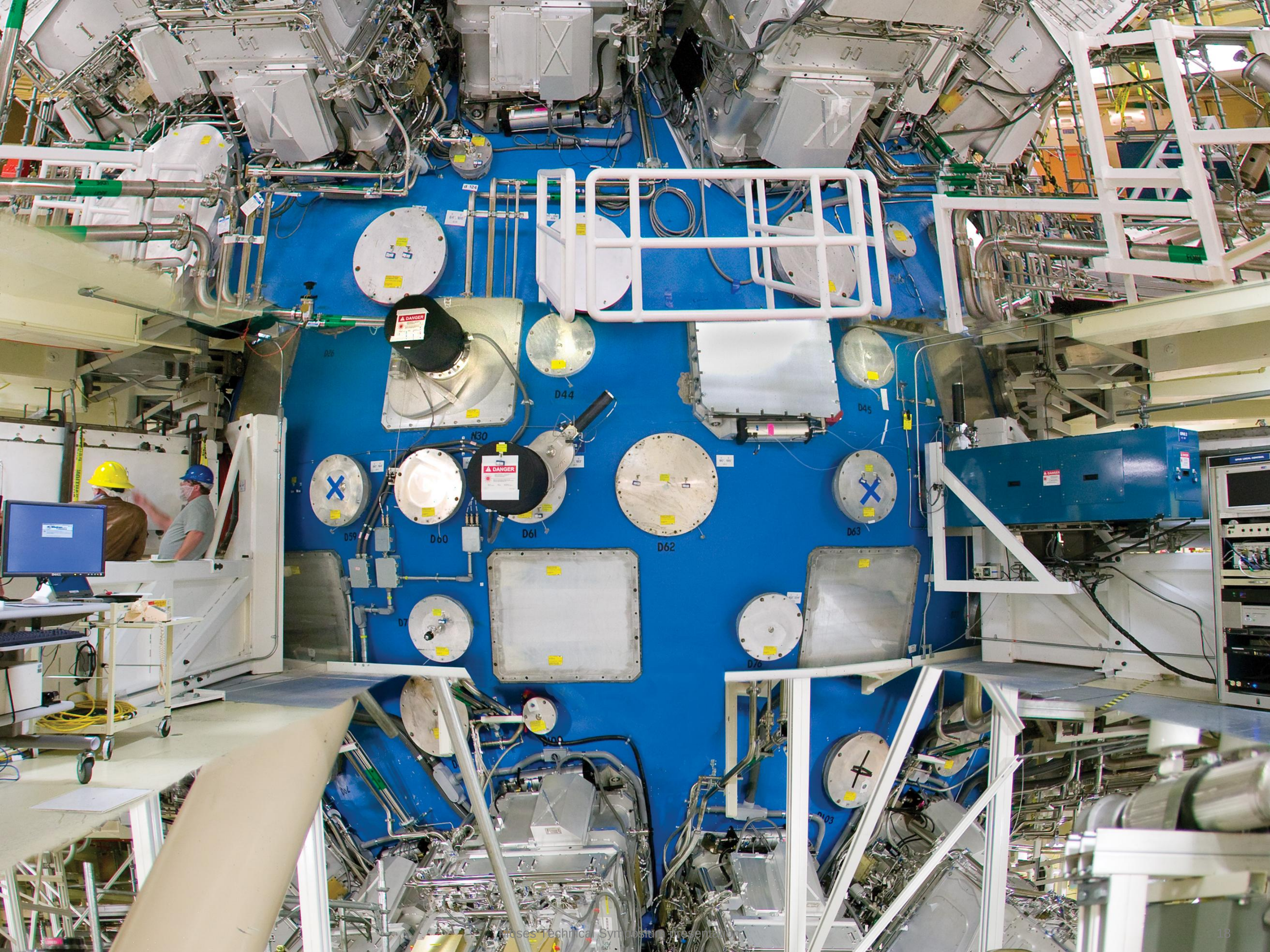
Laser Bay infrastructure




25/2 T
KONECRANES
NIF-0409-16233
23EM/al



Target Chamber Dedication
June 1999


DANGER
DANGER
D44
D45
N30
D59
D60
D61
D62
D63
D76

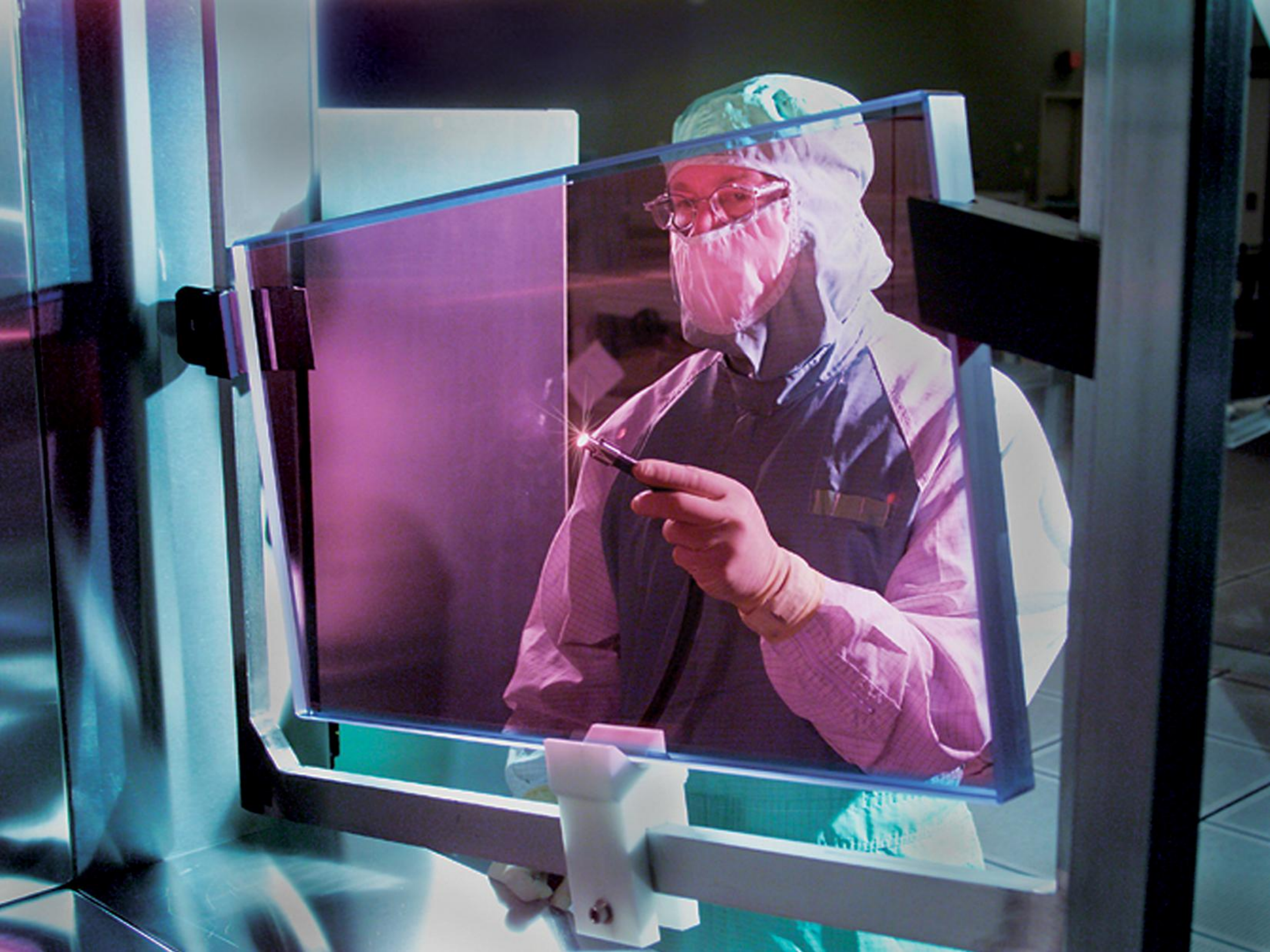

Target
Fabrication
NIF-0509-16343

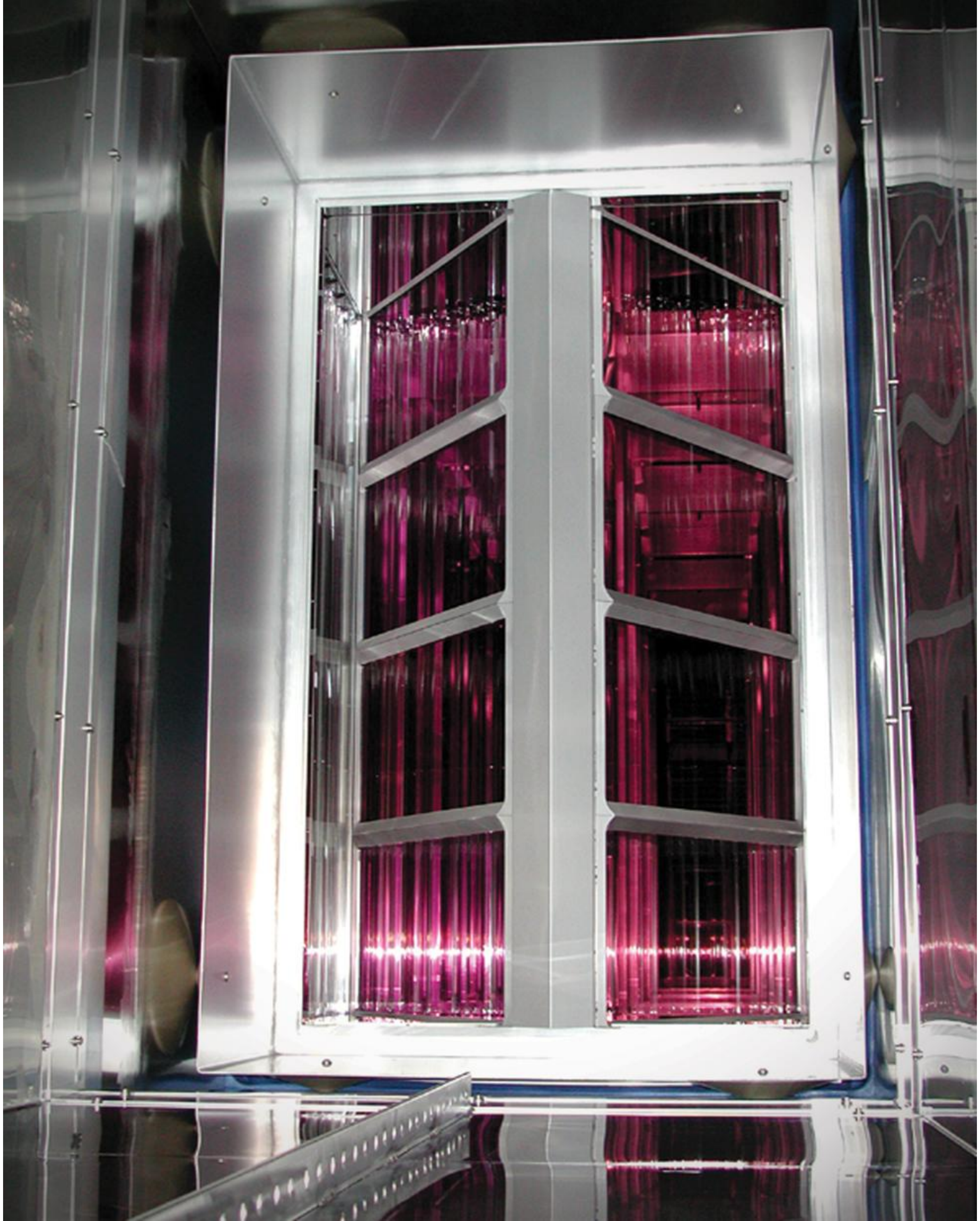

Target
Diagnostics
DUST-HOG
NIF-0509-16342

The 7 Wonders of NIF


NIF
Randy


0814-09
LG40Y19-03
G 40Y19-09
LG40Y19-04
815-02
LG40Y19-05
LG40Y19-07





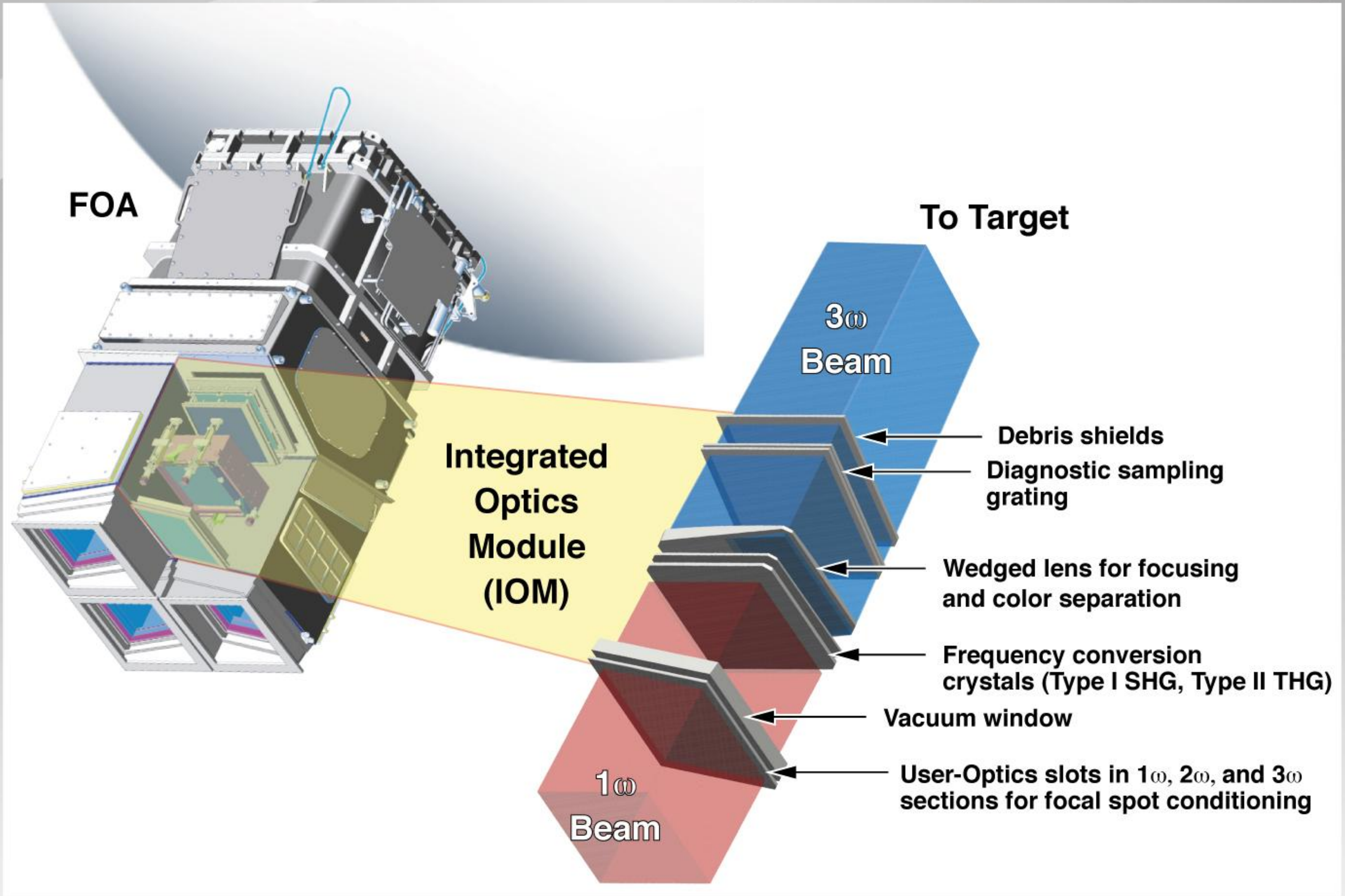
Plasma Electrode Pockels Cell

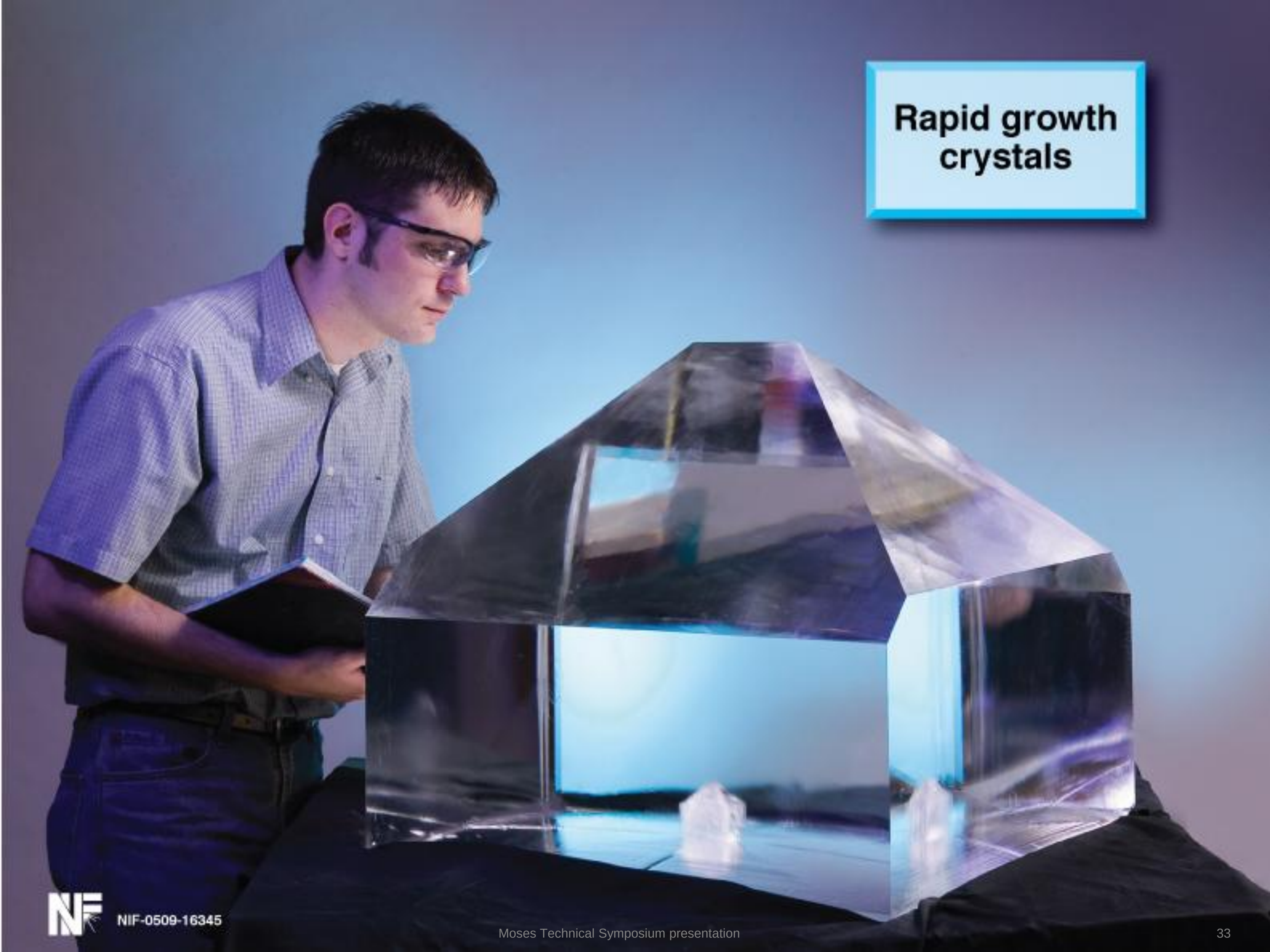
NIF-0509-16348

NIF-0509-16347


Deformable
mirrors
WYKO

The Final Optics Assembly (FOA) combines a number of critical functions into a single compact package

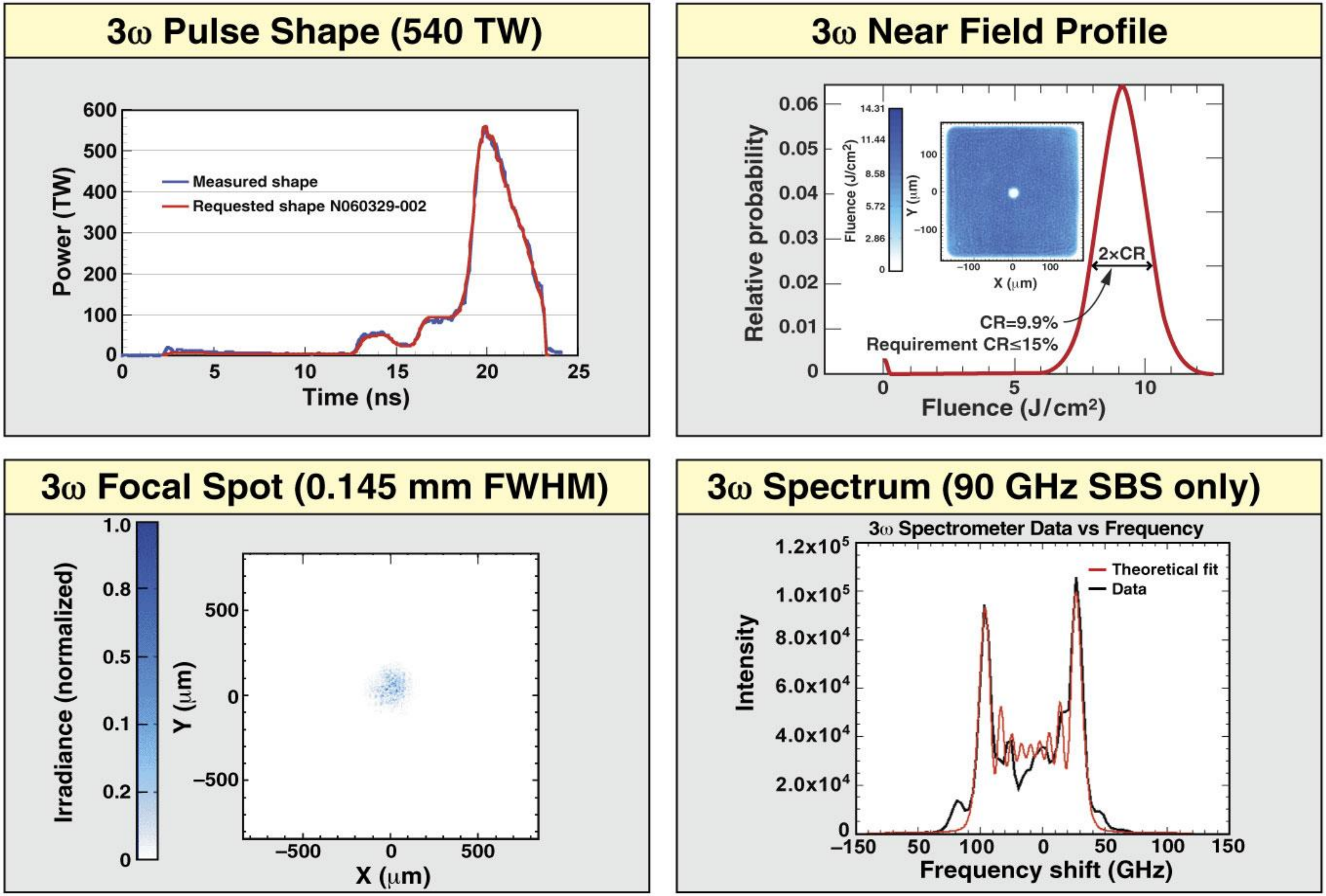



Rapid growth
crystals
NIF-0509-16345

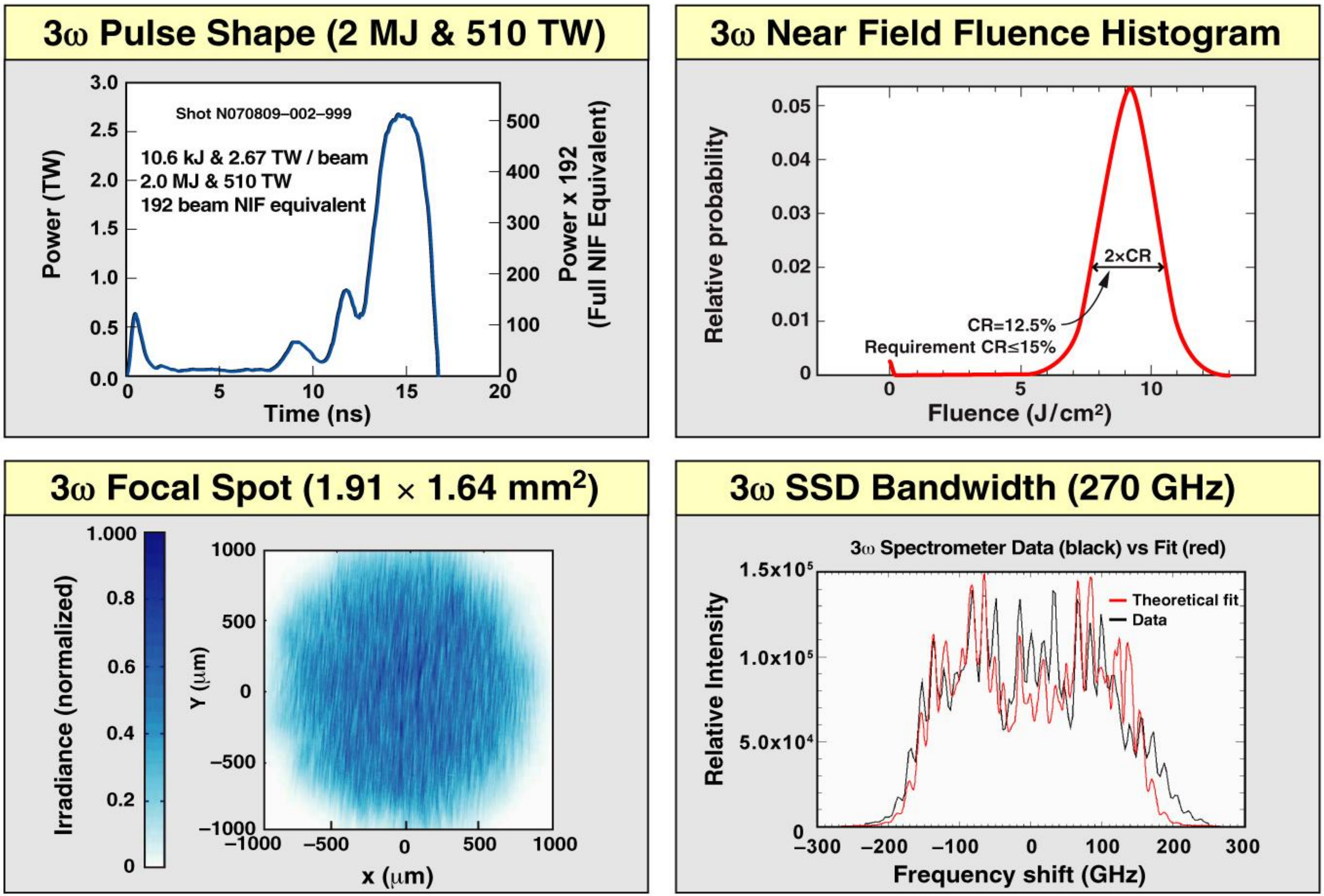

Integrated
control room
NIF-0509-16344


LEAD
OPERATOR

Achieving a small focal spot at high peak power is a necessary precursor to focal spot smoothing

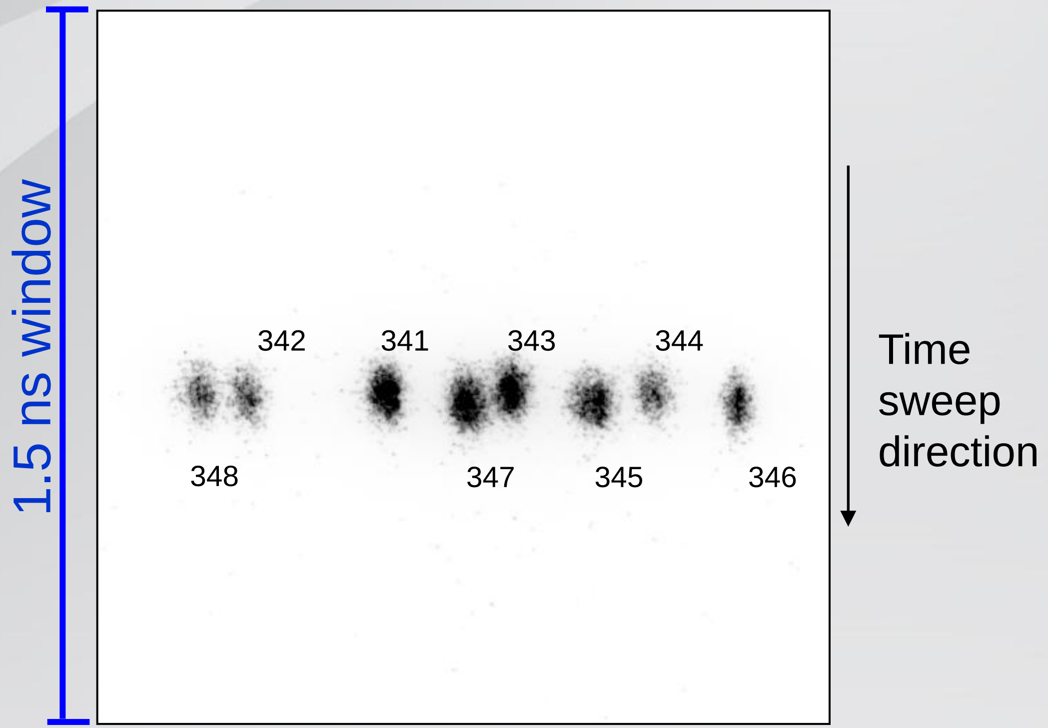


1.8 MJ ignition point design, energy, power, pulse shape & smoothing were achieved simultaneously

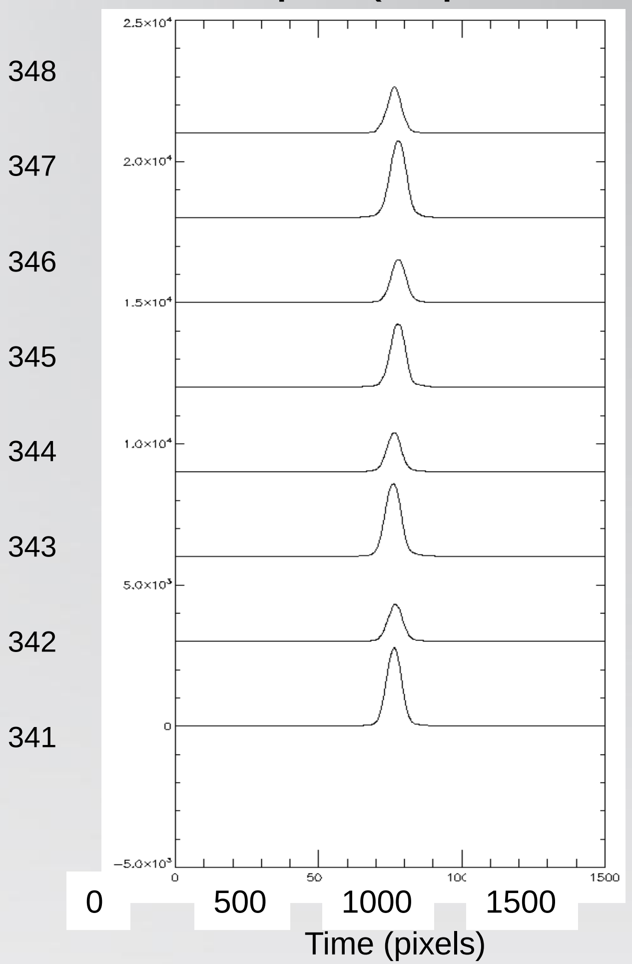


B34 was synchronized to 14ps RMS with an 88ps 50J 3ω impulse (N080602-002-999)

Streak X-ray diagnostic output



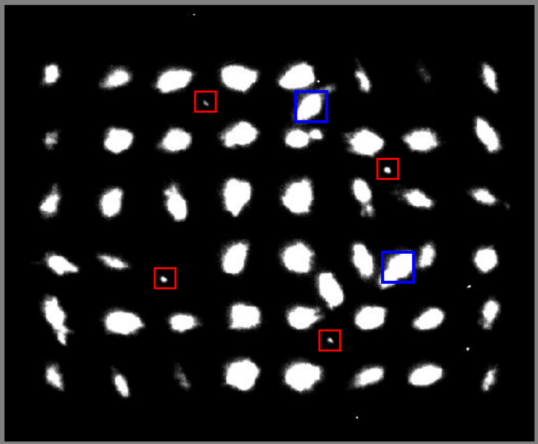
Processed output (88ps FWHM)



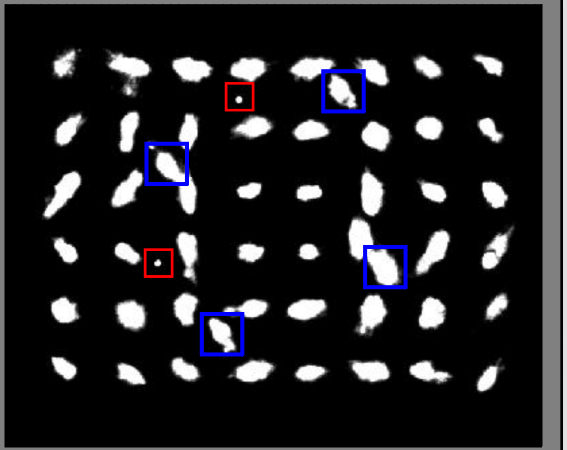
We have met our 30ps synchronization requirement with a
technique that is straight forward to apply to all bundles

Pointing stability was measured on 96 beams (plus 6 fiducial beams) delivered to a flat target with two SXIs

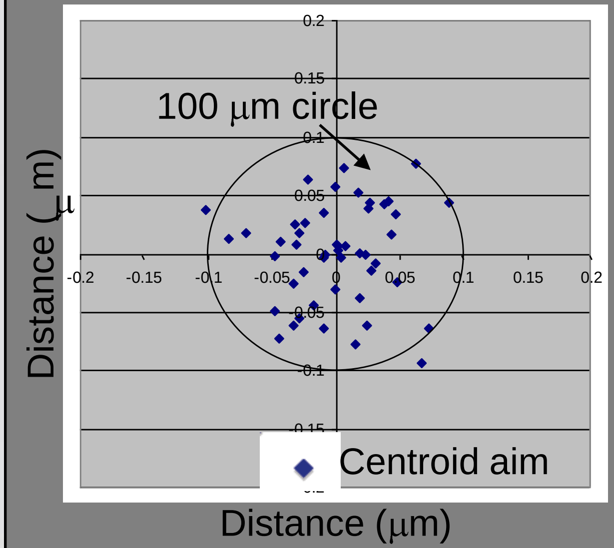
SXI upper



SXI lower



60μm RMS pointing error

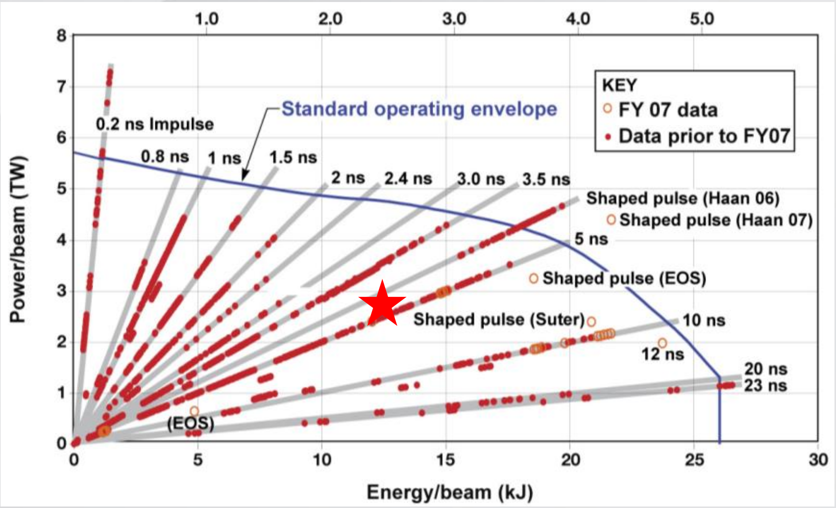


800 microns between focal spots
Shot N090114-002-999

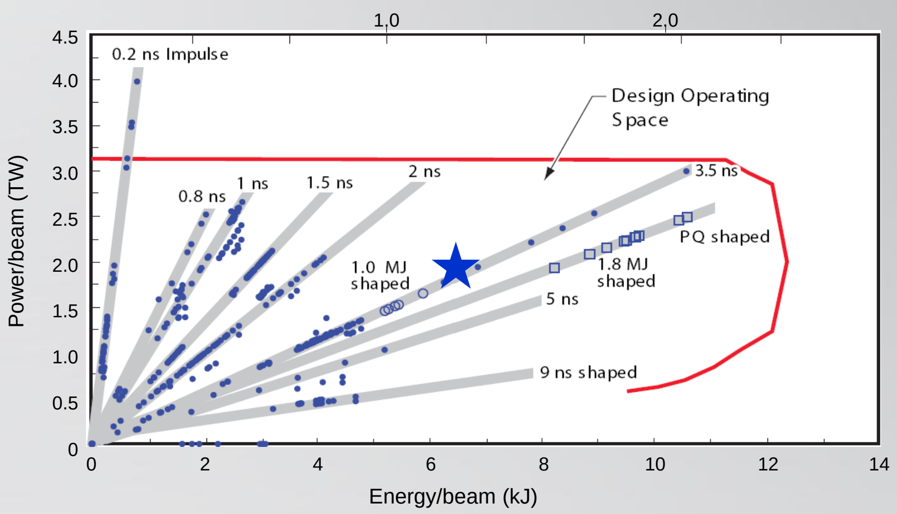
- 8 beam (single bundle) pointing shot completed 12/08
- 96 beam pointing shot series completed 1/09
  - Beam to target pointing was 58μm rms

NIF shots to date have thoroughly explored the design operating space at 1ω and 3ω

1ω 192 beam Energy (MJ)



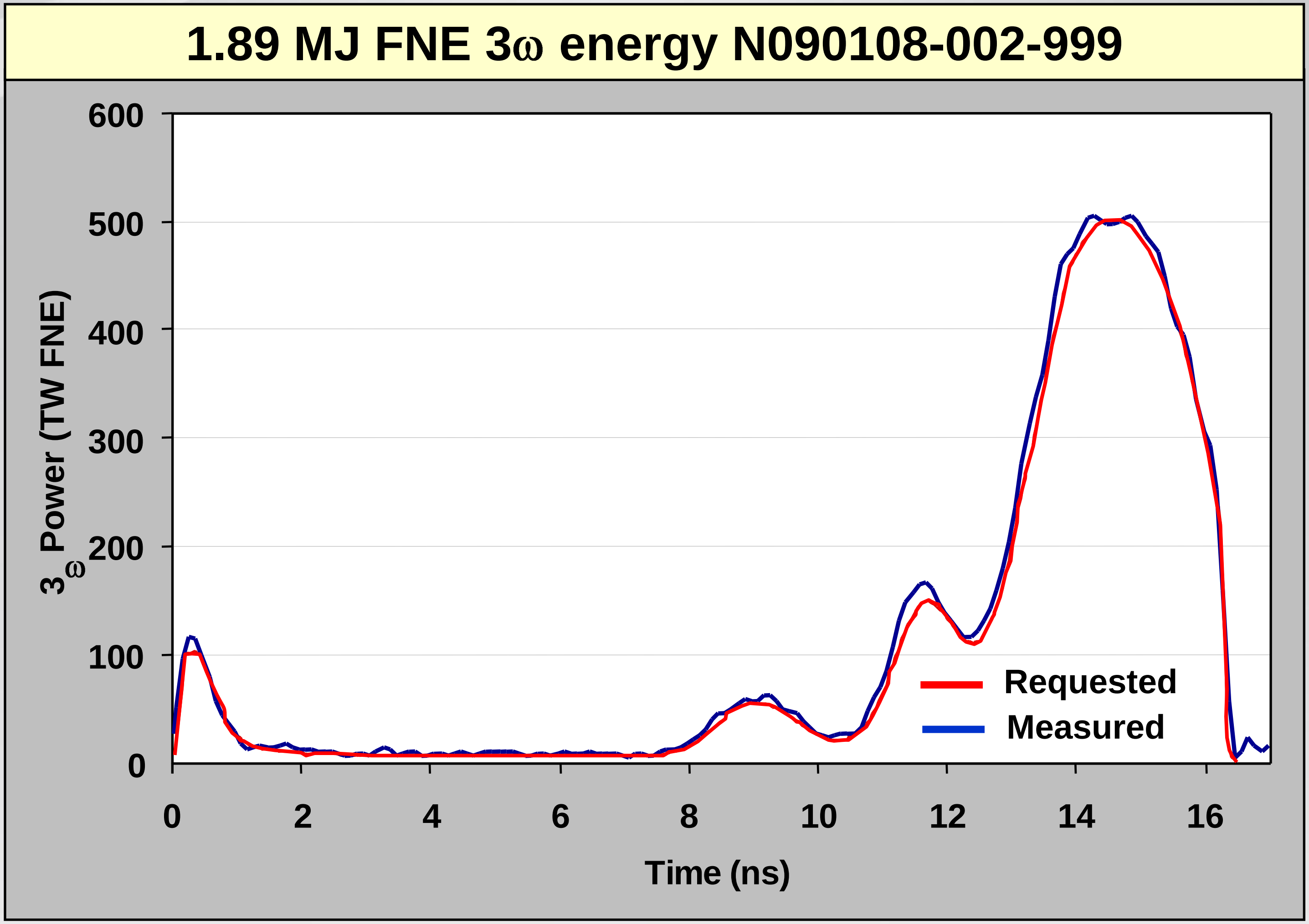
3ω 192 beam Energy (MJ)



★ =NIC Rev3.1 Be 1ω, 12.2kJ/beam, 2.6TW/beam

★ =NIC Rev3.1 Be 3ω, 6.4kJ/beam, 1.88TW/beam

One quad of the laser was used to demonstrate the full NIF energy at 3ω delivered to TCC with the designer-specified focal spot and all smoothing methods used simultaneously



Energy and power on Q34B are multiplied by 48 quads to obtain FNE

NIF Partners:
National Laboratories, Academia, Industry, and the International Community

Partners in NIF Enterprise: $1.8B Contracted

NIF is ready for ignition experiments

We have demonstrated

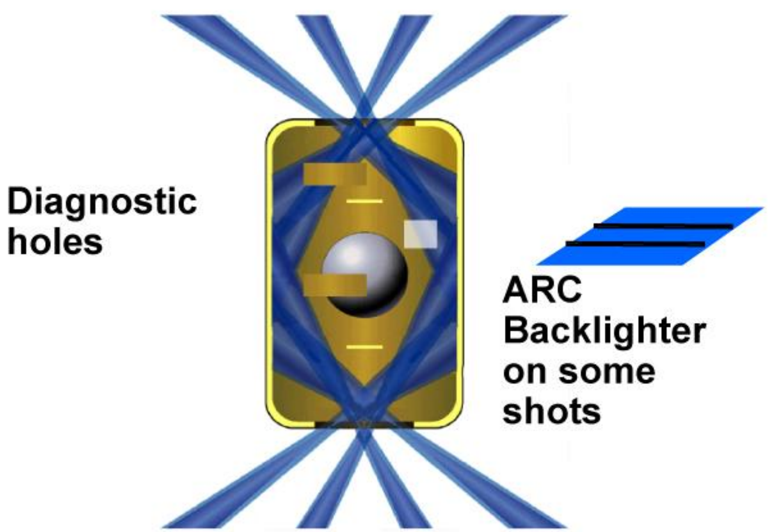
- All beam conditioning techniques required for ignition simultaneously at 1.8 MJ, 500 TW FNE in PDS and for a NIF quad TCC
- NIC power balance levels and synchronization requirements (B34)
- RMS pointing of 64 μm, significantly better than the 100μm RMS point design requirement
- Wavelength tuning between the inner and outer cones
- NIF operation at 3ω at > 1.1 MJoule

NIF Master Strategy

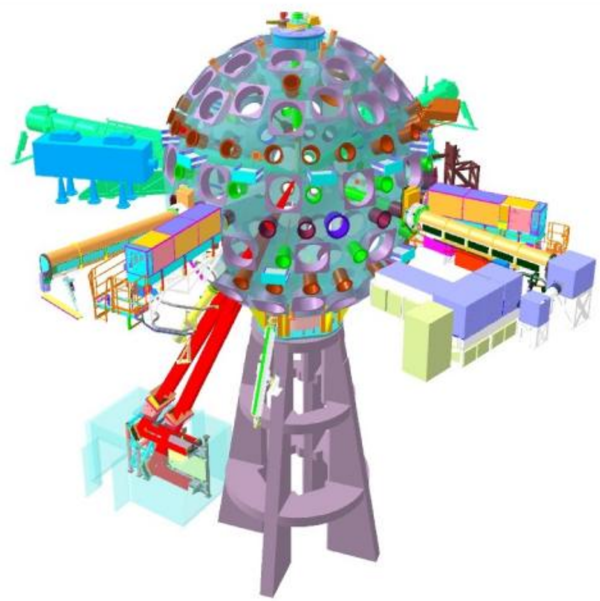
National Ignition Campaign goals

Execute a credible ignition campaign starting in FY2010 with the goal of demonstrating at least 1MJ fusion energy

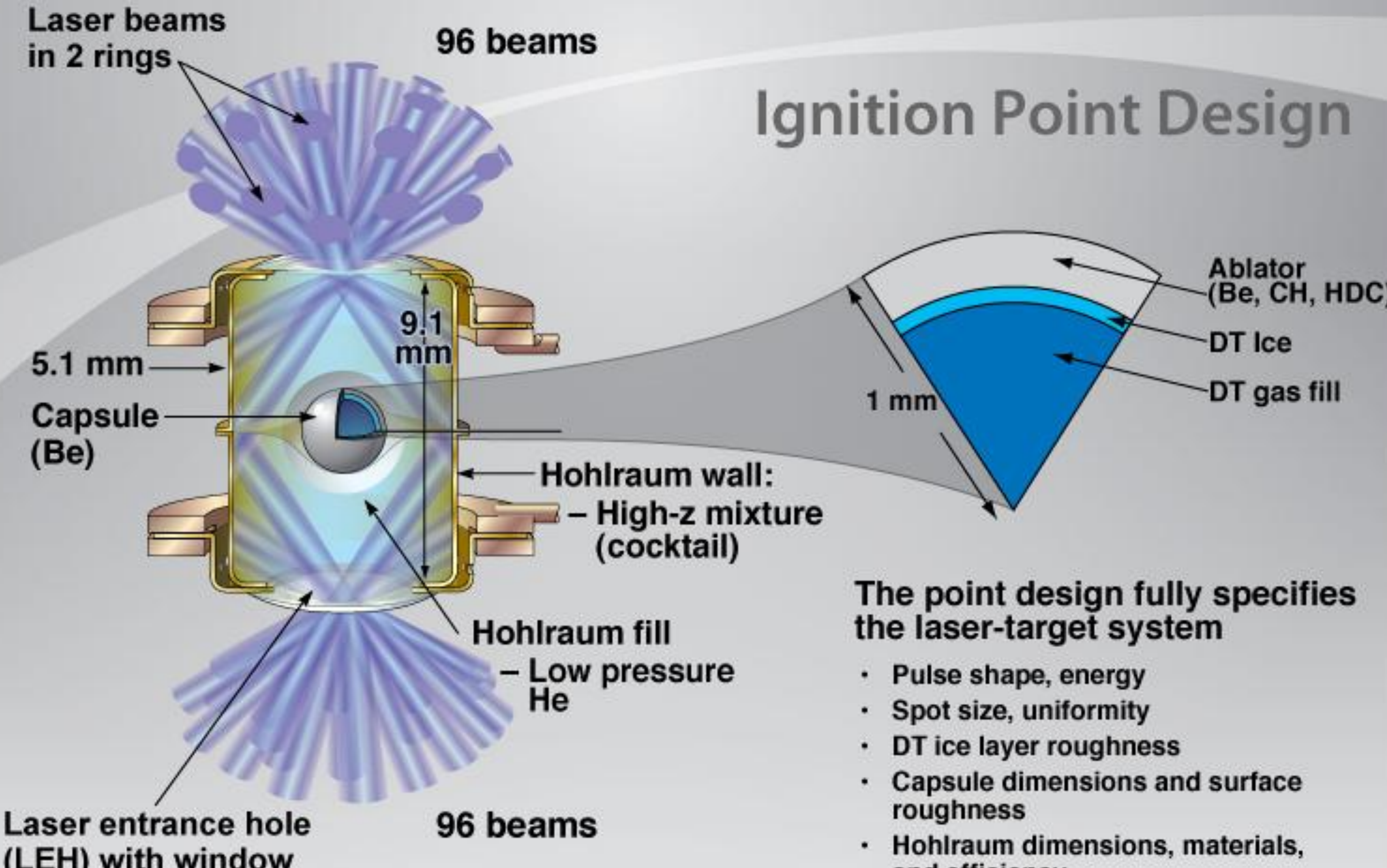
Layered implosion, THD or DT



Demonstrate a reliable and repeatable ignition platform for use in stockpile stewardship experiments by 4Q FY2012



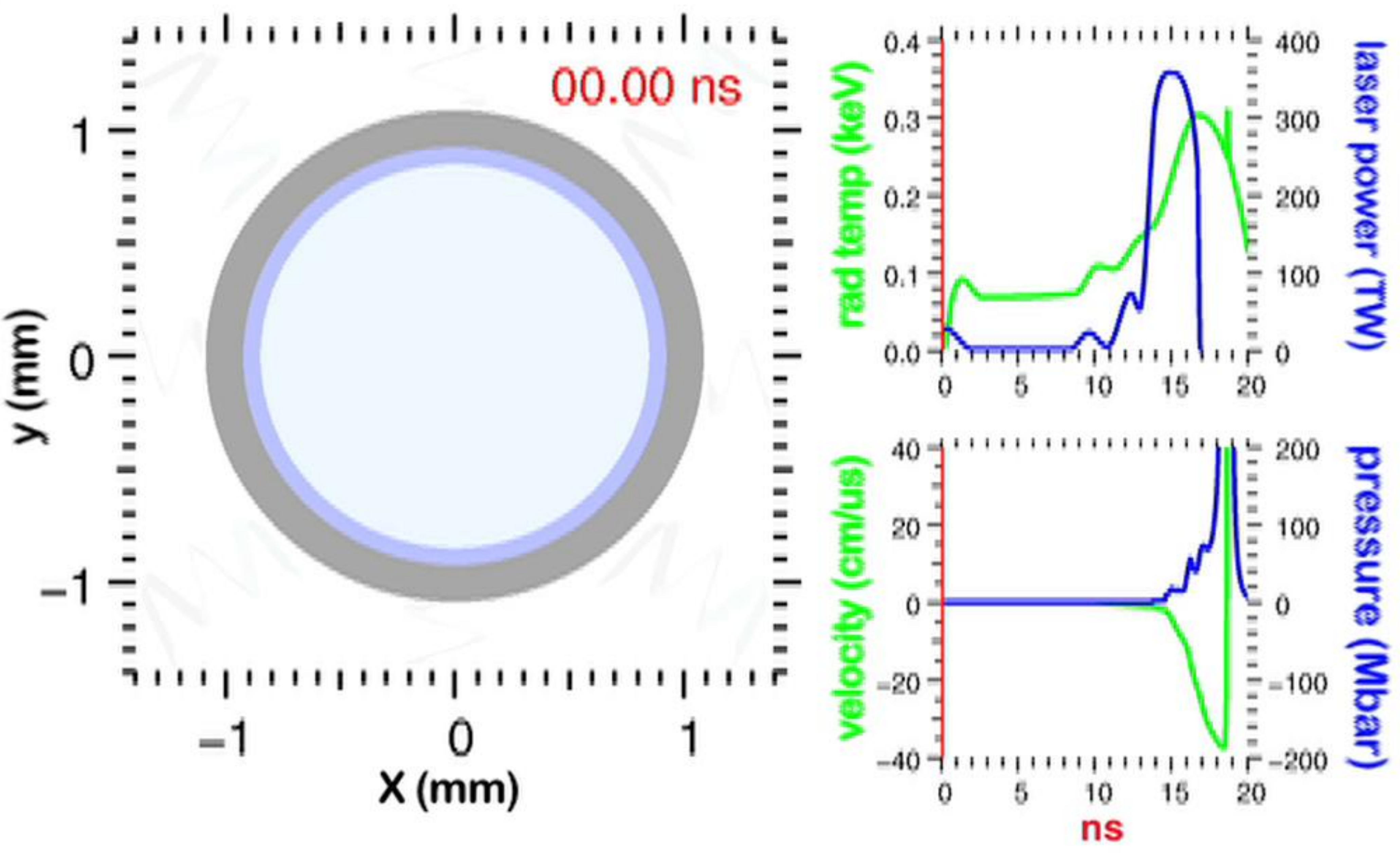
Ignition Point Design



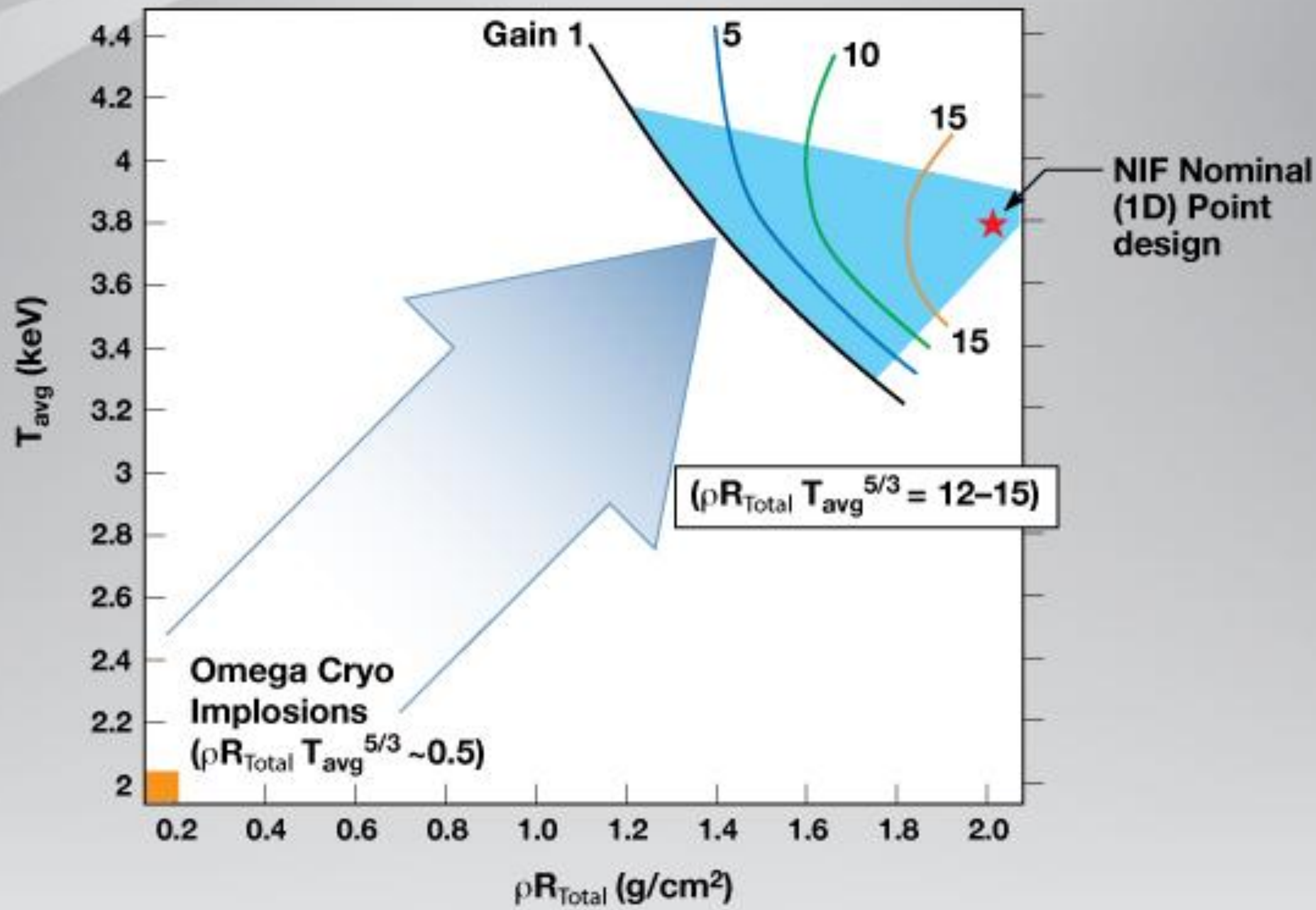
The point design fully specifies the laser-target system

- Pulse shape, energy
- Spot size, uniformity
- DT ice layer roughness
- Capsule dimensions and surface roughness
- Hohlraum dimensions, materials, and efficiency
- Target thermal and position stability
- Diagnostics

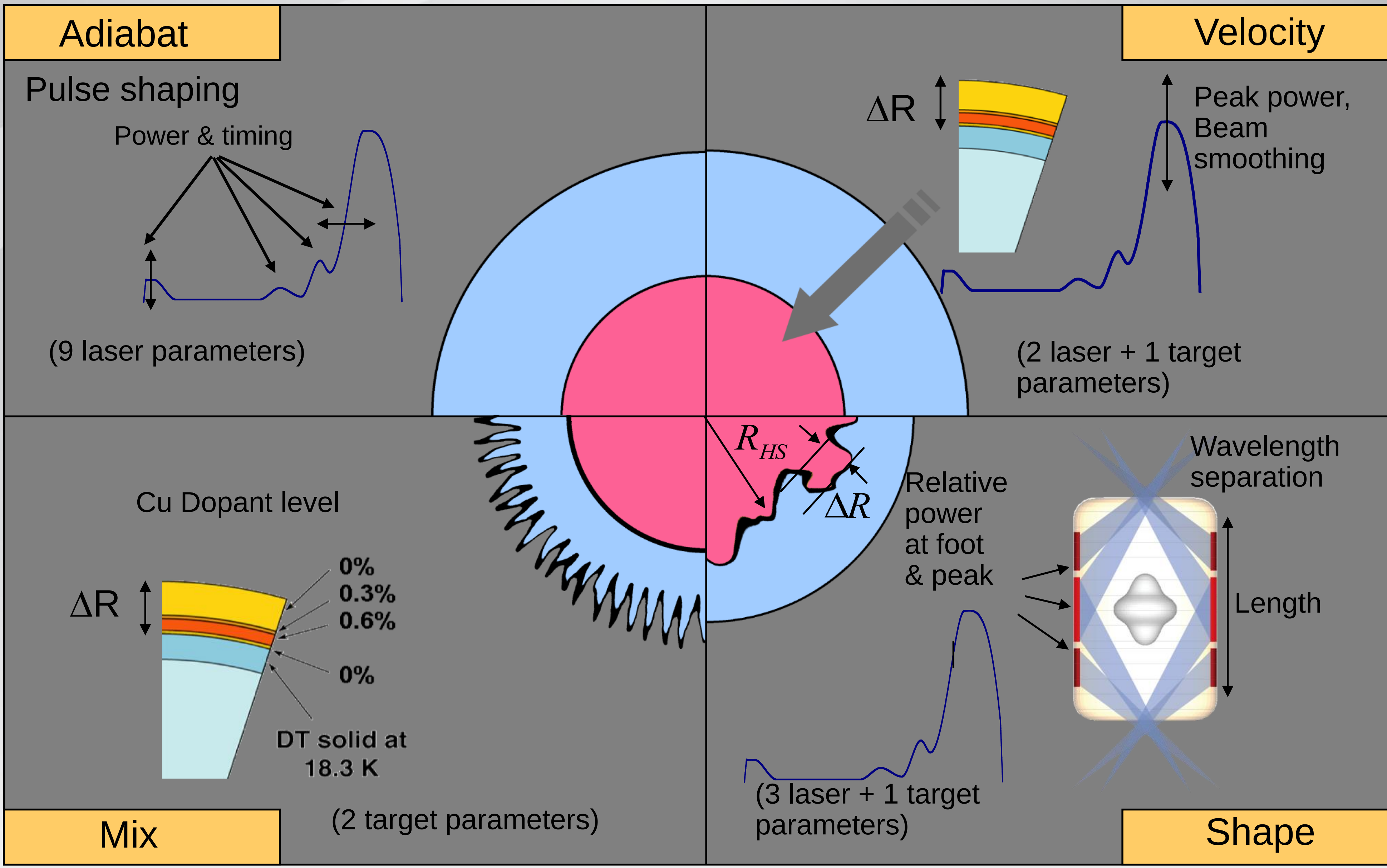
Capsule Implosion



NIF will access density and temperature conditions required for ignition



Tuning strategy



IPT's commission each functional element

More Diagnostics

Increasing Precision

Better Surrogacy

Planar targets

Laser
Precision: – $P_L(t)$ pointing – Smoothing

Optical diagnostics

Gas filled targets

Hohlraum	
T_R	$P_L(t)$
LPI	CPP, $\Delta\omega$
P_2	$\Delta\lambda$
M band	Cu dopant
Hot e^-	

Optical & X-ray diagnostics

Gas & liquid targets

$Y_n < 10^{13}$

Capsule	
Symm	L, $P_{in:out}$
Velocity	P_{peak}
Entropy	$P_L(t)$, ΔR Cu doping

Optical & X-ray diagnostics

THD Solid layer targets

$Y_n < 10^{15}$

Tritium Layer (THD)	
Mix	Cu/mass
ρR	Shock timing
T	Vel/mix

Hardened X-ray & nuclear diagnostics

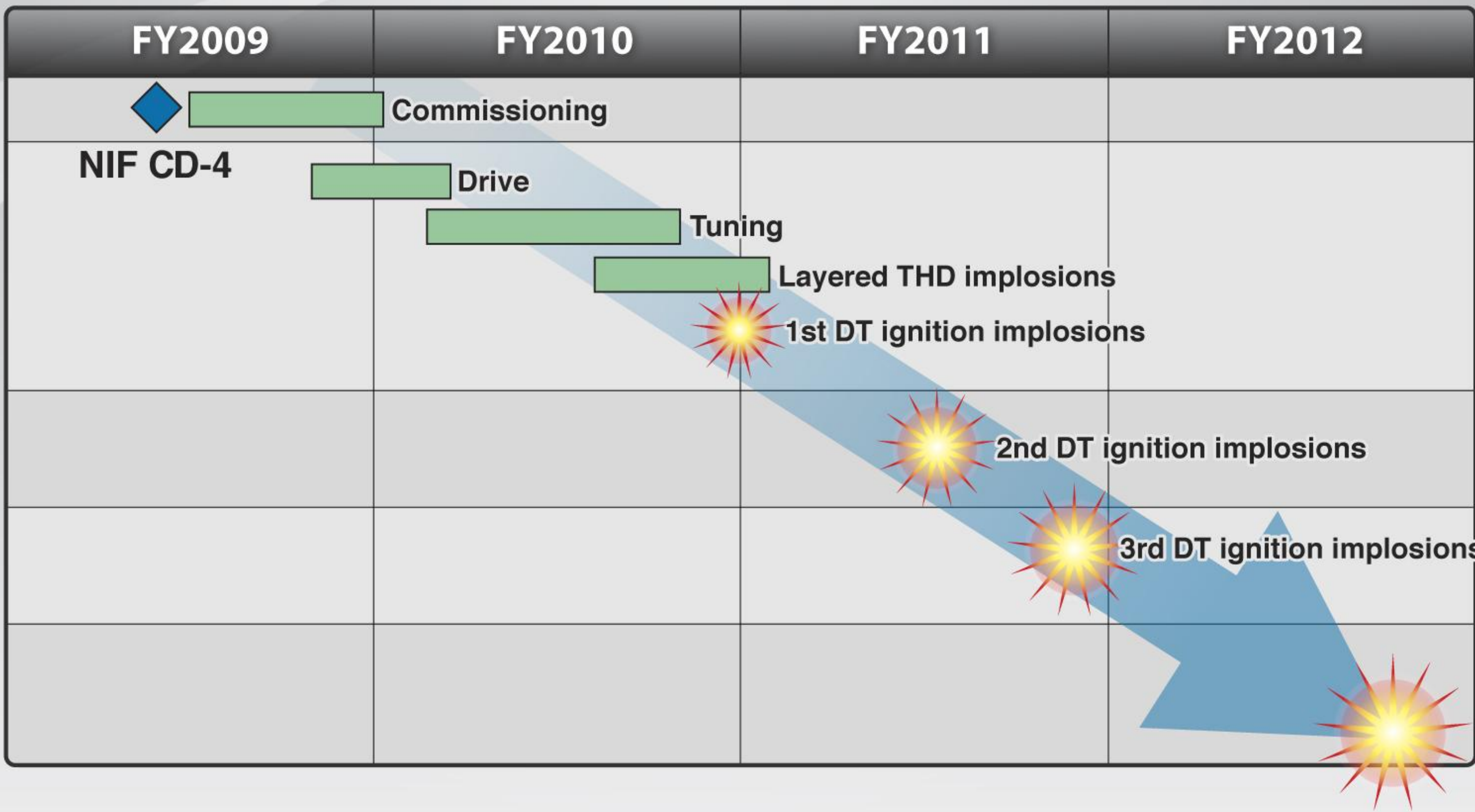
DT

$Y_n > 10^{16}$

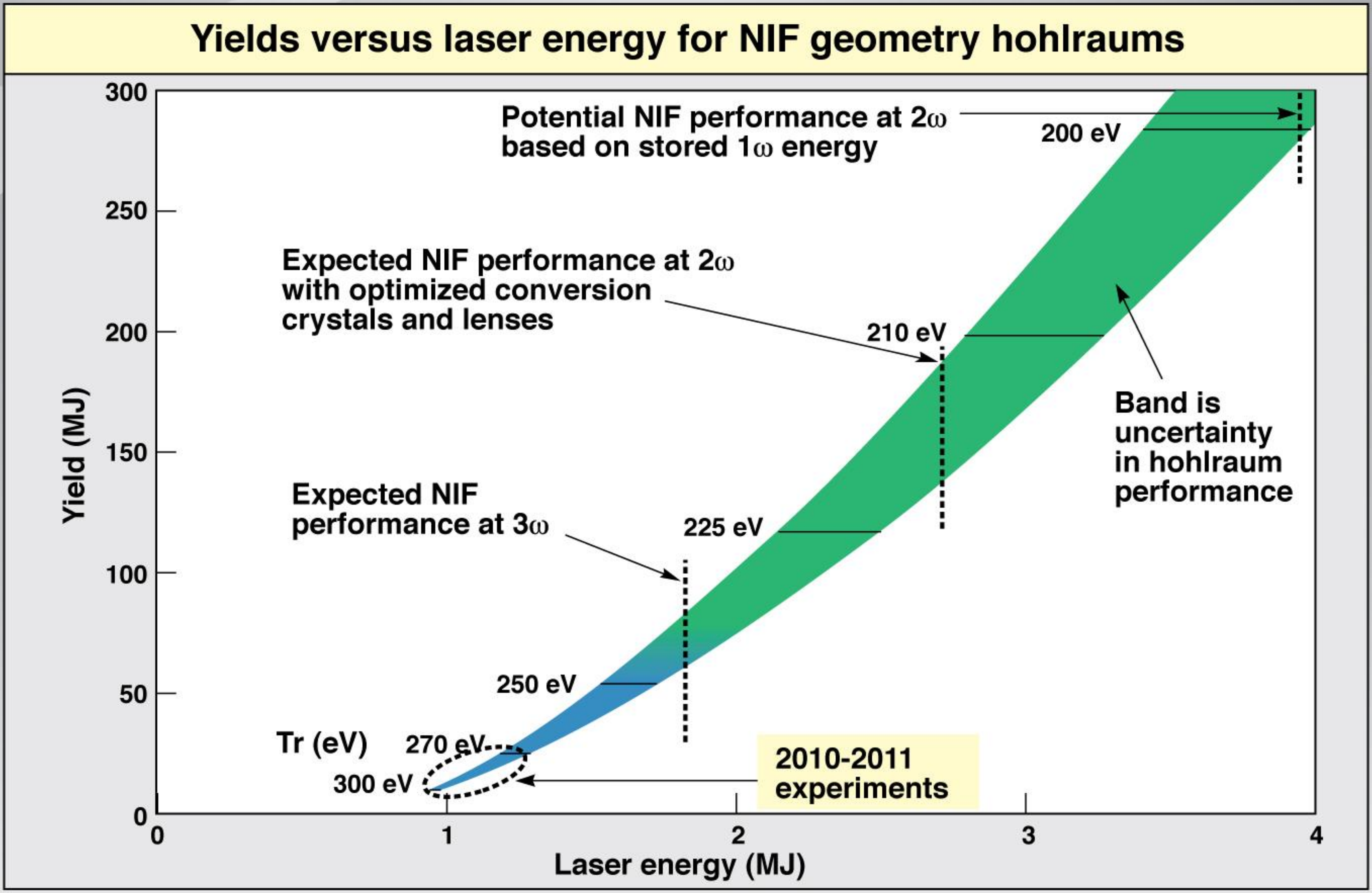
DT Burn, Yield

Nuclear diagnostics

The path to NIF ignition experiments

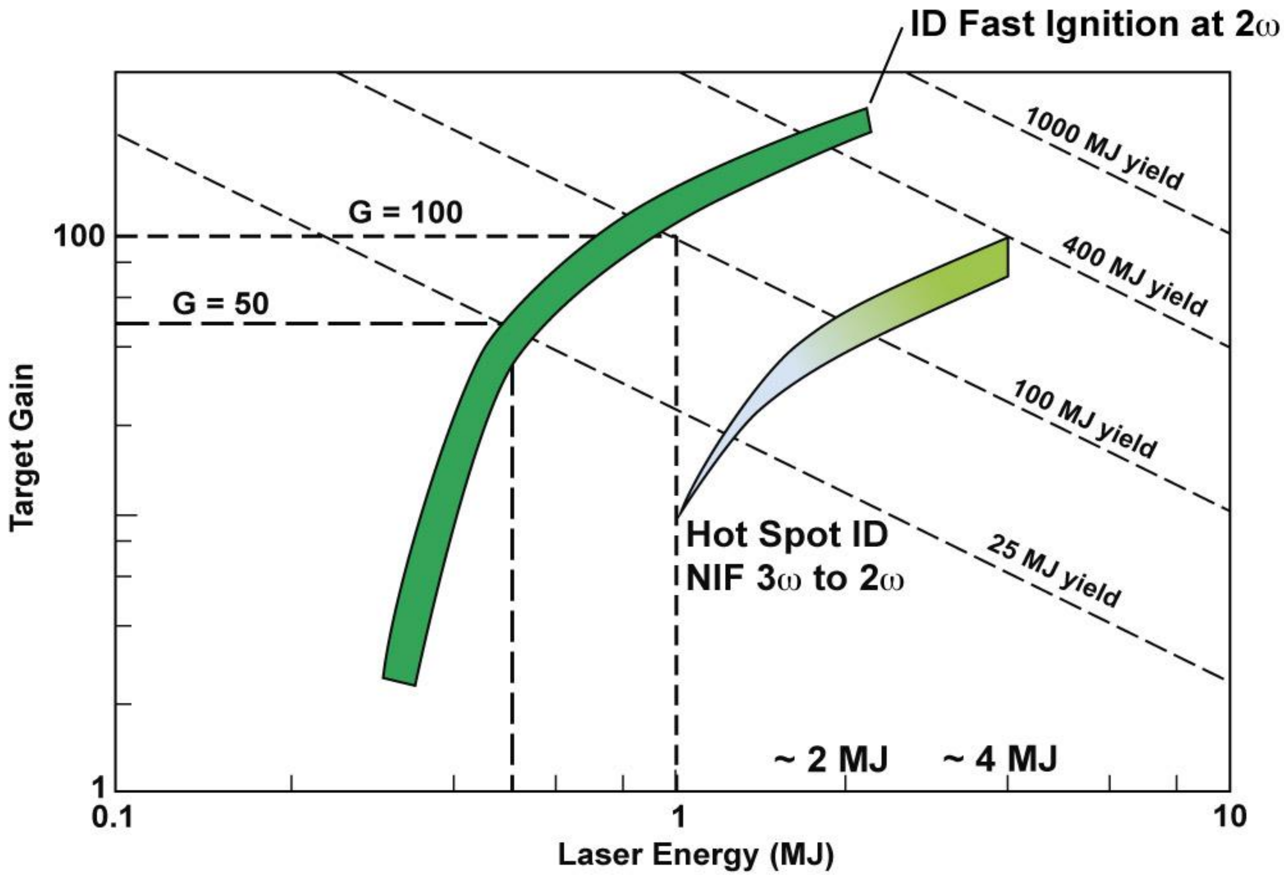


Ultimately, yields well in excess of 100 MJ may be possible on NIF



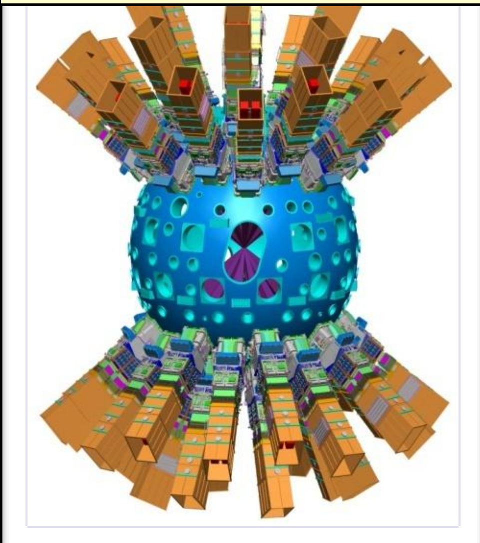
Indirect Drive Fast Ignition has higher gains at a given laser energy and relaxed symmetry requirements

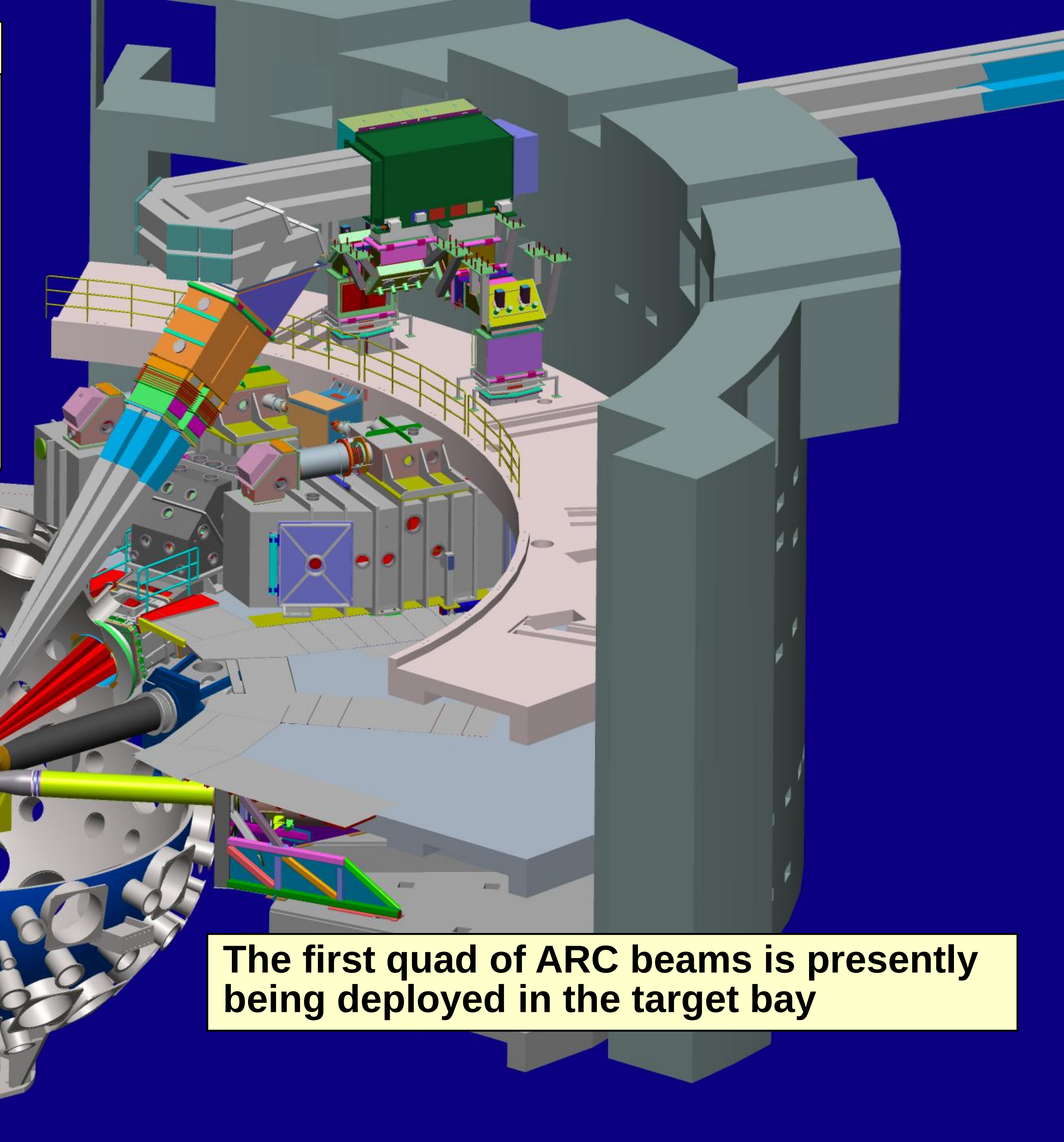
The National Ignition Facility



NIF-0107-13251r1_L1
26ES/mfm

NIF Laser Beams





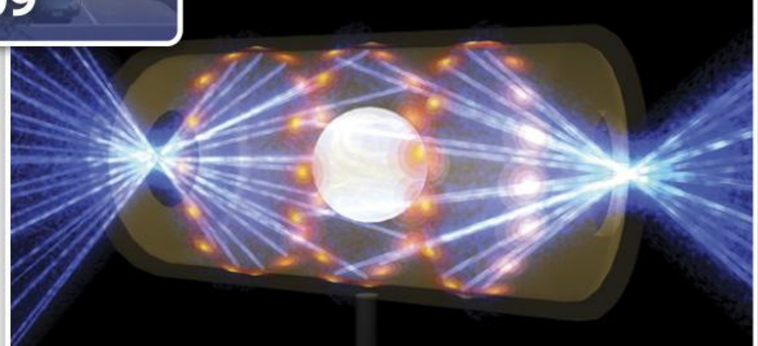
The first quad of ARC beams is presently being deployed in the target bay

NIF Master Strategy

NIF Project

Completion in 2009

National Ignition Campaign



2006-2012

National User Facility

2009-2030

Achieving ignition at the National Ignition Facility can be a defining moment for the world's energy future

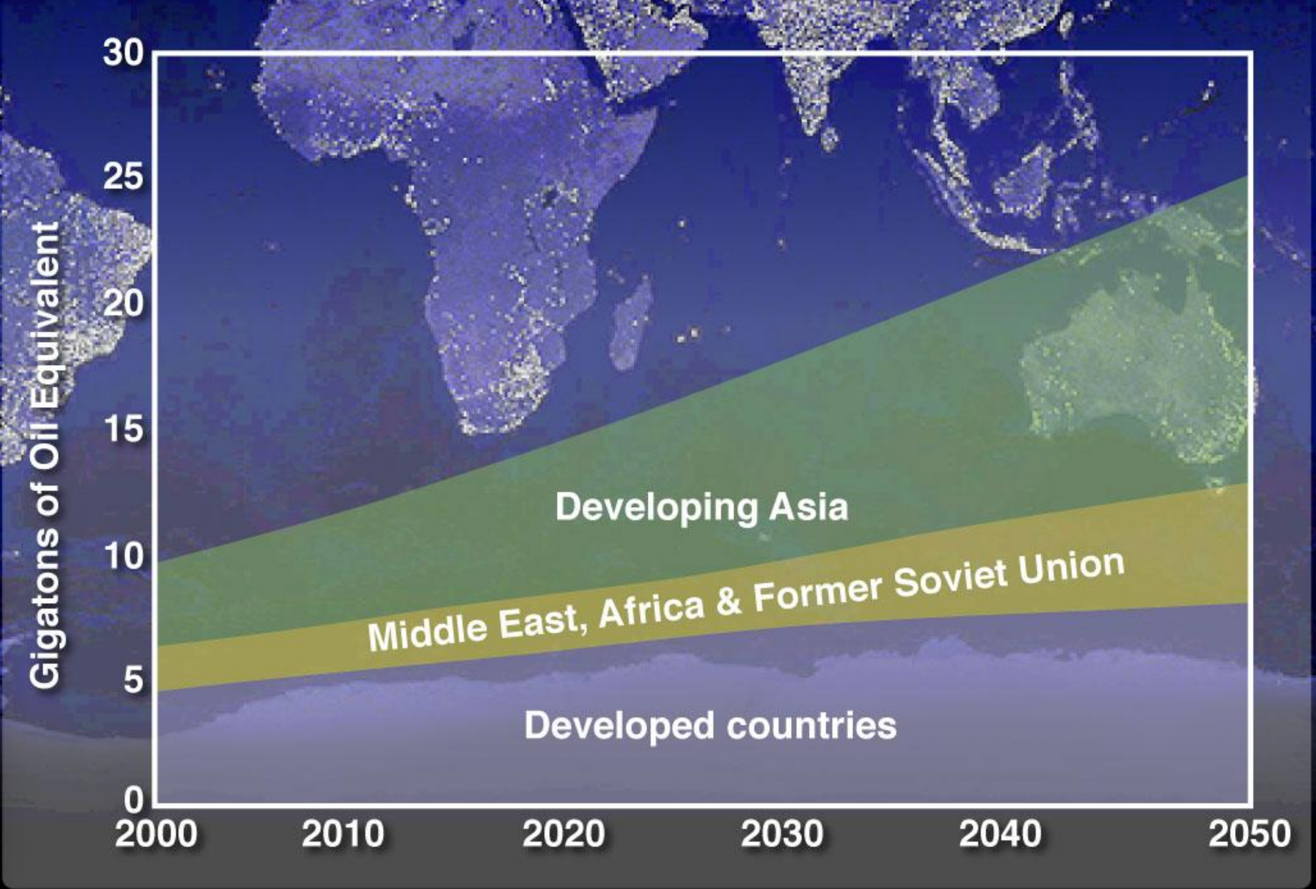
We are developing "LIFE," a compelling approach for carbon-free baseload power

Clean energy: Humankind's challenge

Global Factors

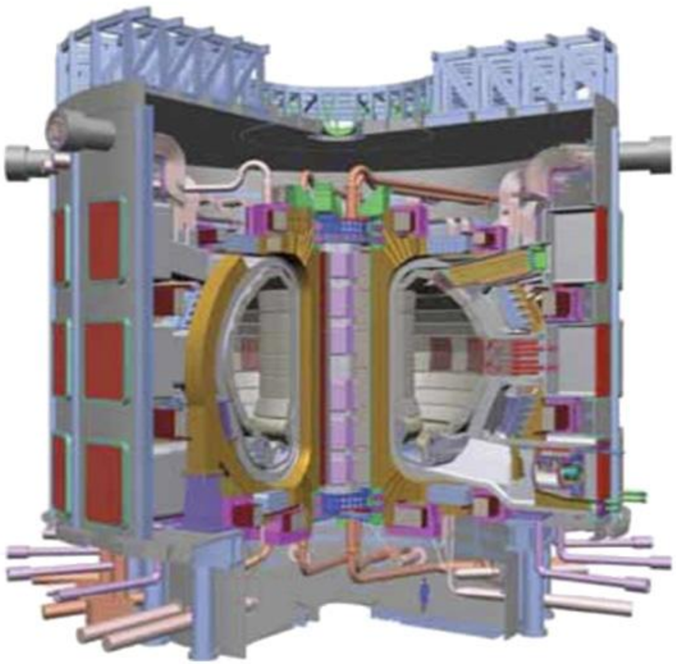
- Population increase
- Developing countries
- Resource depletion
- Climate change

This challenge must be resolved and solved today...Not 50 years from now



There are two major approaches for fusion energy

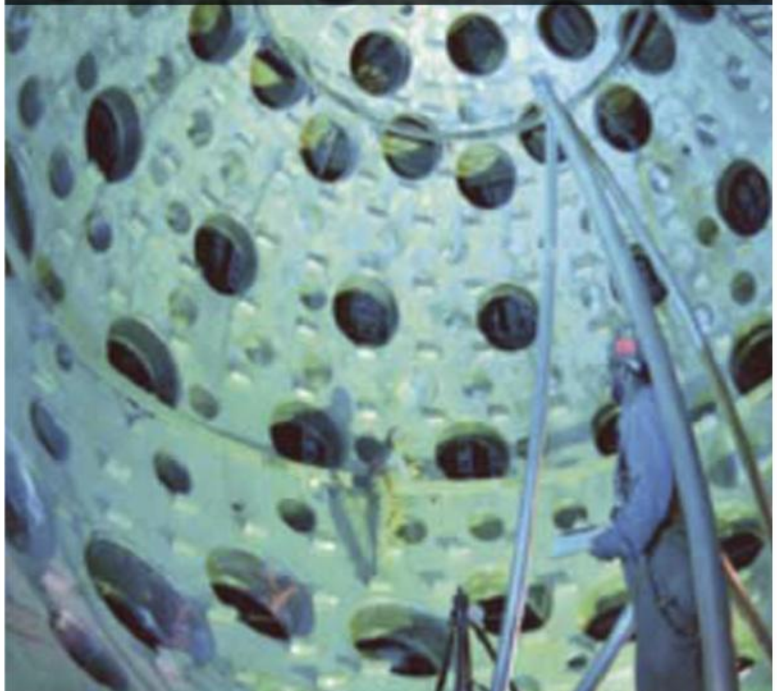
Magnetic Fusion Energy (1951)



First plasma 2018

$$Q = \frac{P_{fusion}}{P_{external}} \sim 10$$

Inertial Fusion Energy (1960)

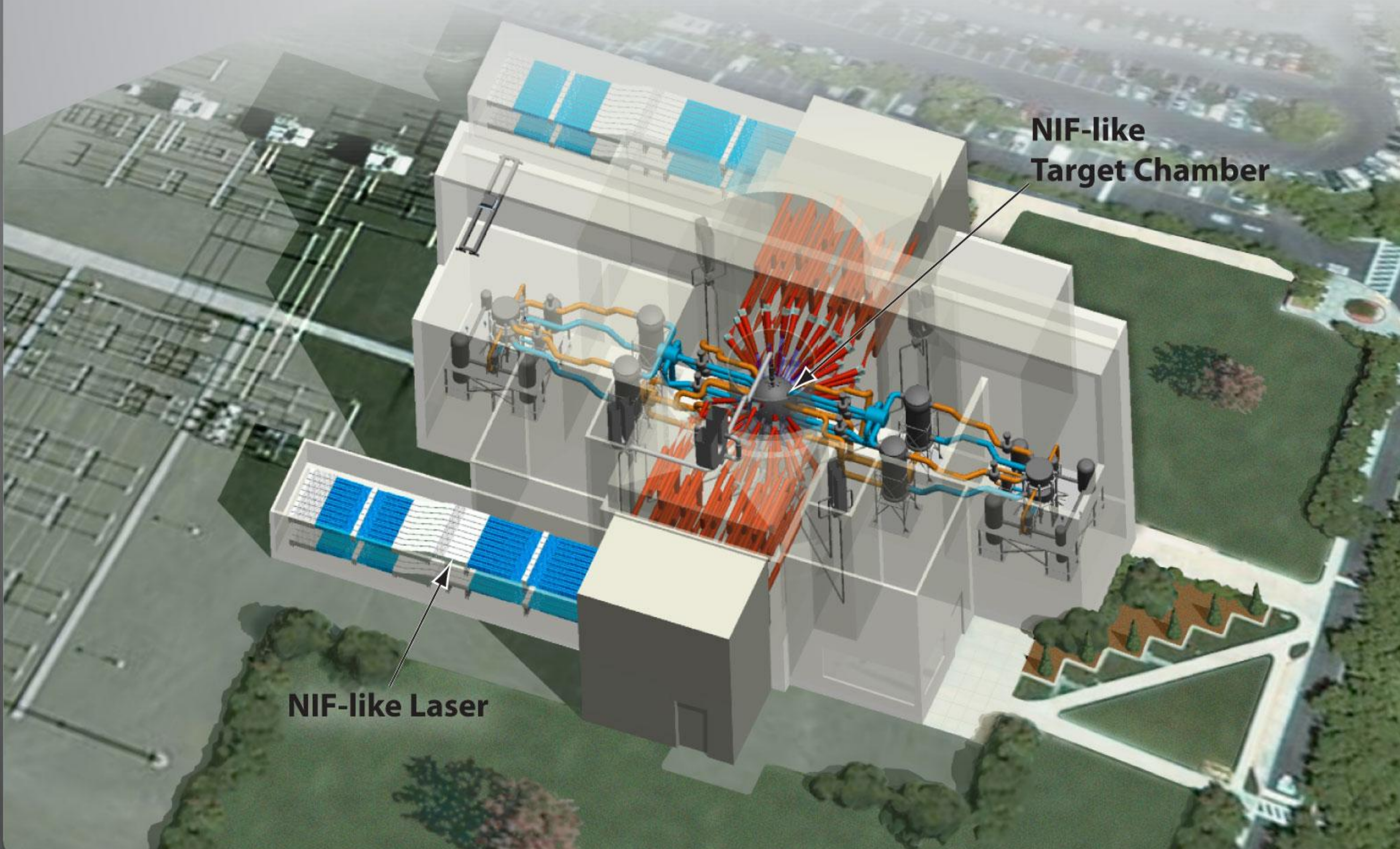


First DT ignition campaign 2010

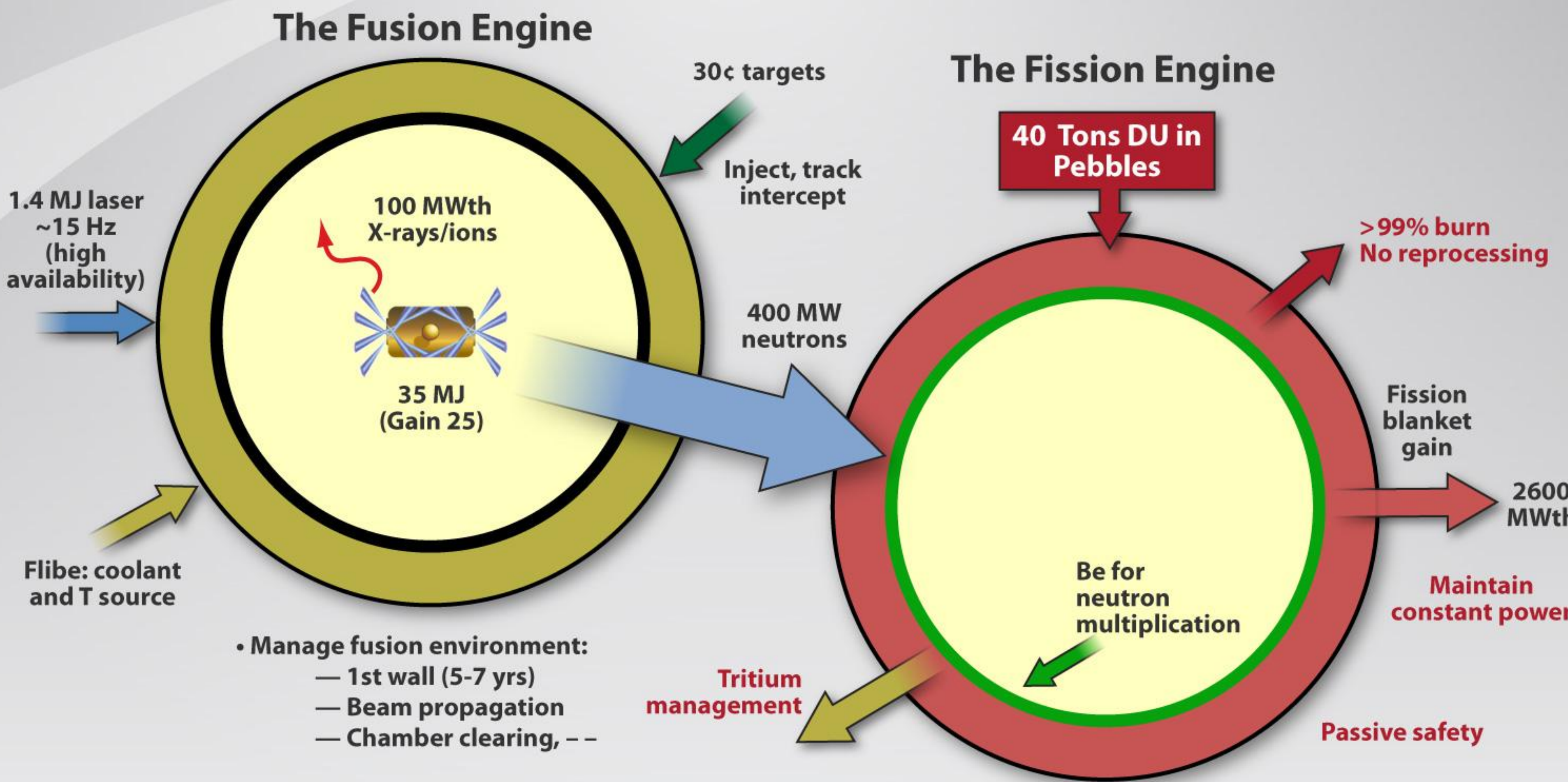
$$G = \frac{E_{fusion}}{E_{laser}} \sim 10\text{–}20$$

Challenges include making it safe, reliable, and cost effective

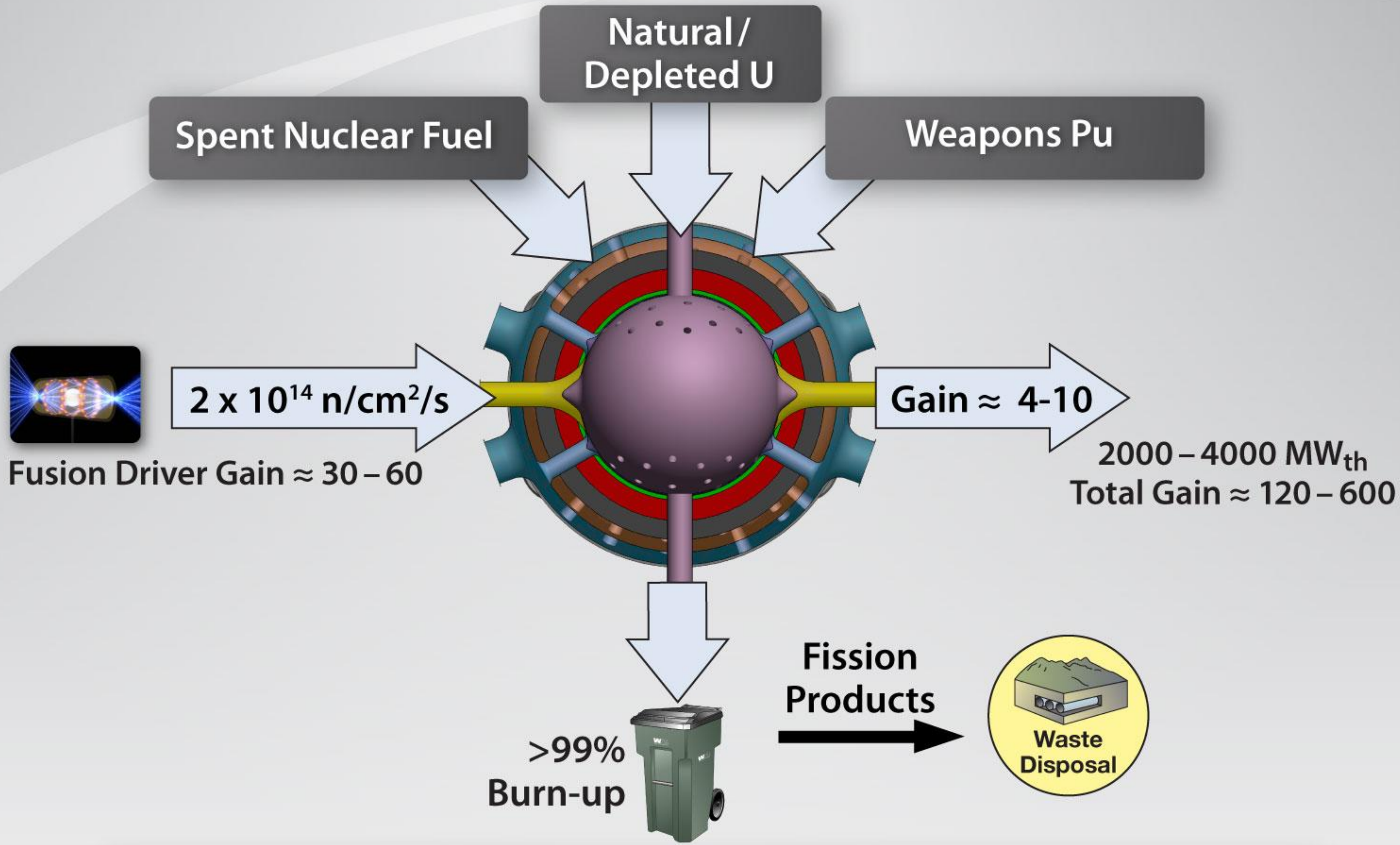
A LIFE engine comprises a NIF-like laser system and a point source of neutrons



LIFE divides naturally into a Fusion and Fission engine with different and distinct challenges



LIFE energy and material flow



LIFE is once-through, "complete" burn-up closed fuel cycle

LIFE: Laser Inertial Fusion-based Energy

- Sustainable carbon-free energy
- Burns depleted uranium, SNF and excess weapons grade plutonium
- Always subcritical and passively safe
- Minimizes need for repositories
- No enrichment
- Significant non-proliferation advantage

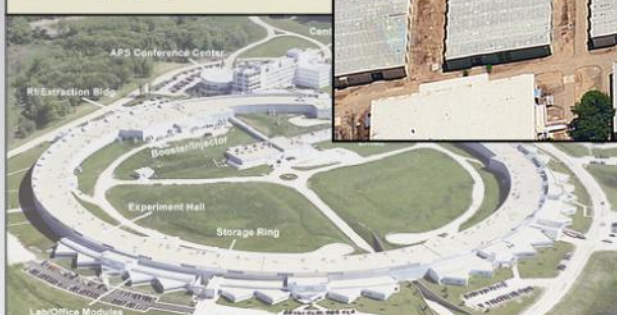
More importantly, it closes the nuclear fuel cycle

CERN

Chandra x-ray Observatory

NIF will be a Premier International Center for Experimental Science

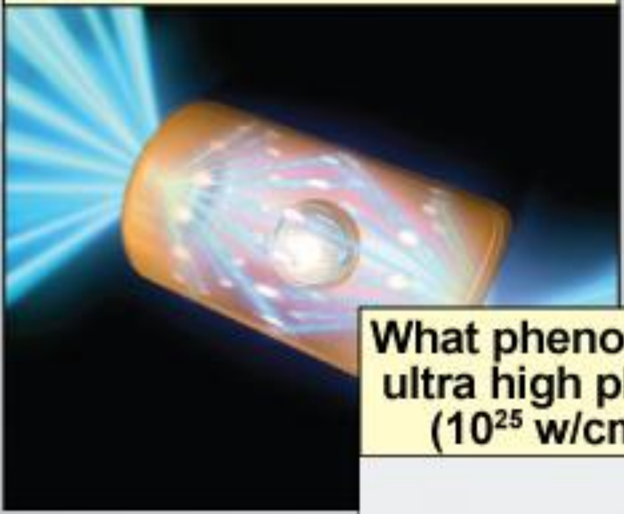
APS



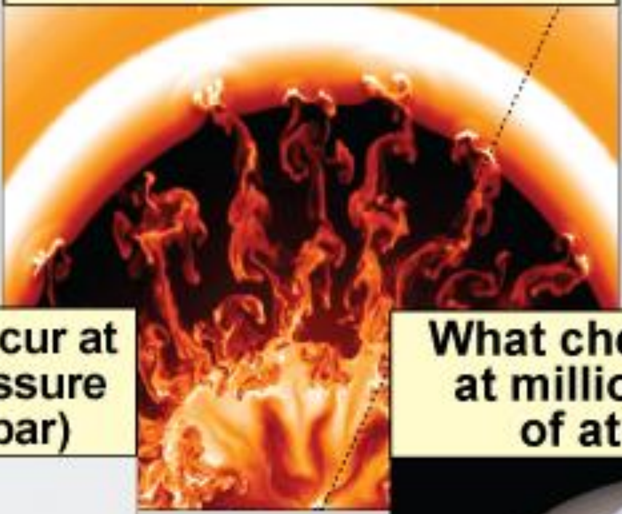
SLAC

Compelling scientific questions for NIF

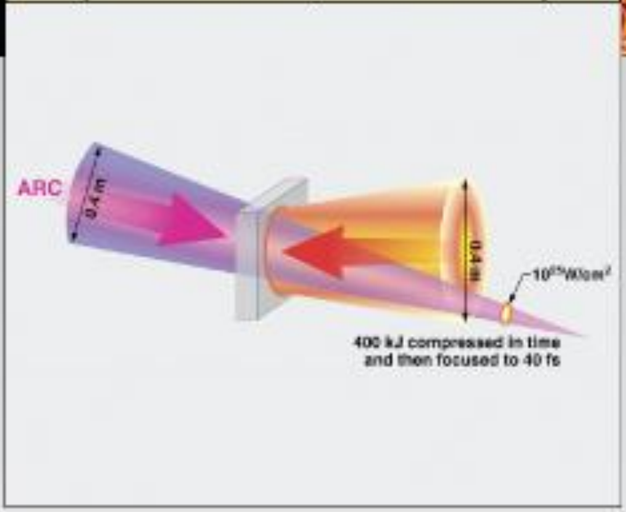
Can we demonstrate laboratory ignition?



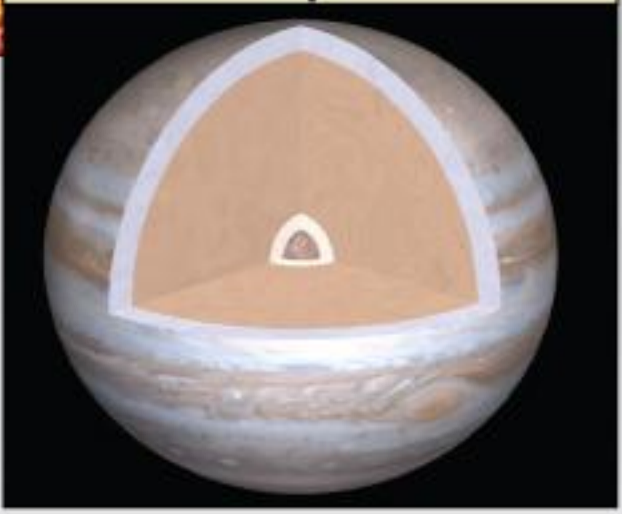
How are elements with Z>26 created?



What phenomenon occur at ultra high photon pressure (10^{25} w/cm^3, 10^{10} M bar)



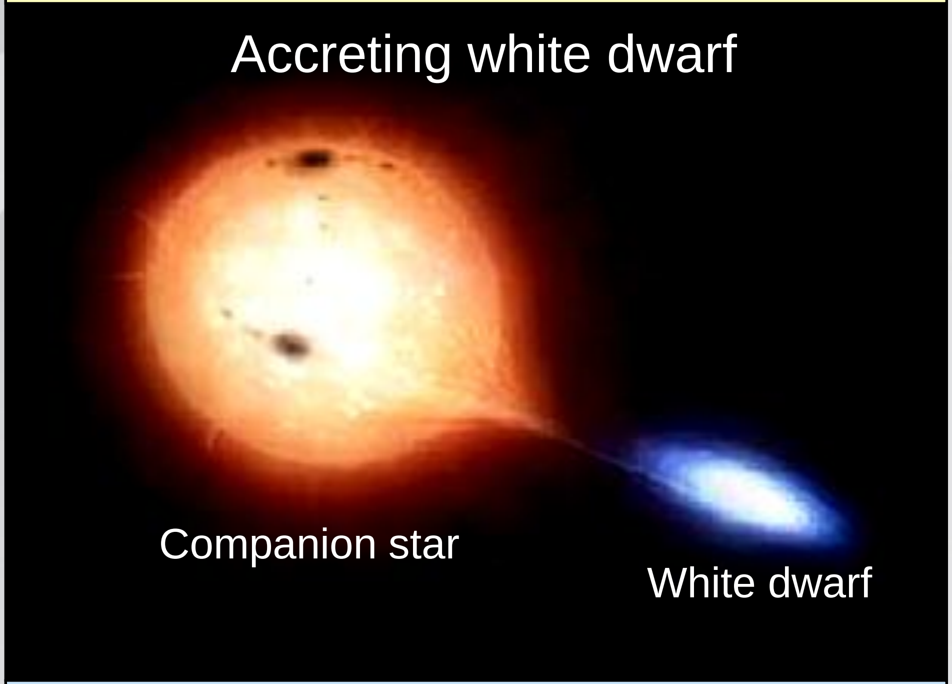
What chemistry occurs at millions to billions of atmopheres?



Supernovae come in two general categories

Type 1A: Thermonuclear	Type II: Core Collapse

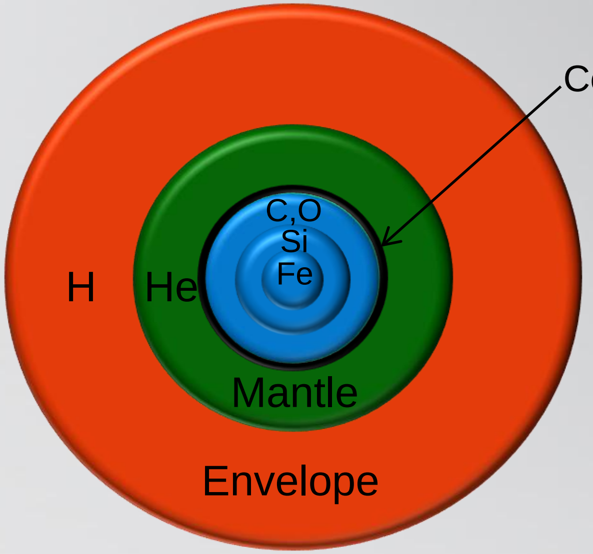
Type 1A: Thermonuclear



- Involve $M \sim M_{sun}$ stars
- Optically brighter
- Standardized candles
- Serve as distance indicators

Type II: Core Collapse

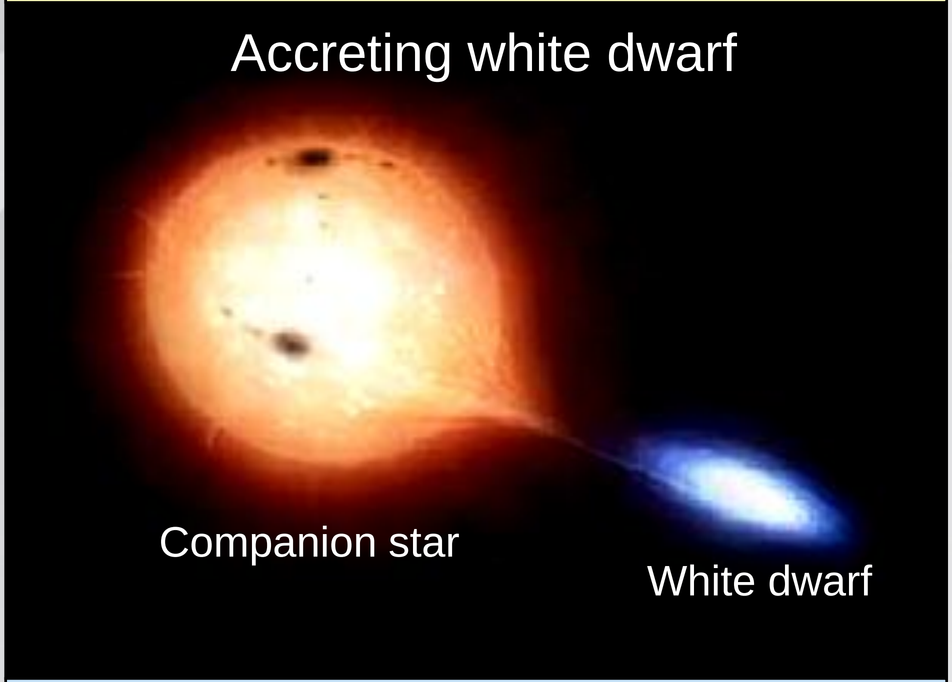
Fe core in massive star collapses



- Involve $M >> M_{sun}$ stars
- More energetic
- More frequent
- Leaves a neutron star behind

Supernovae come in two general categories

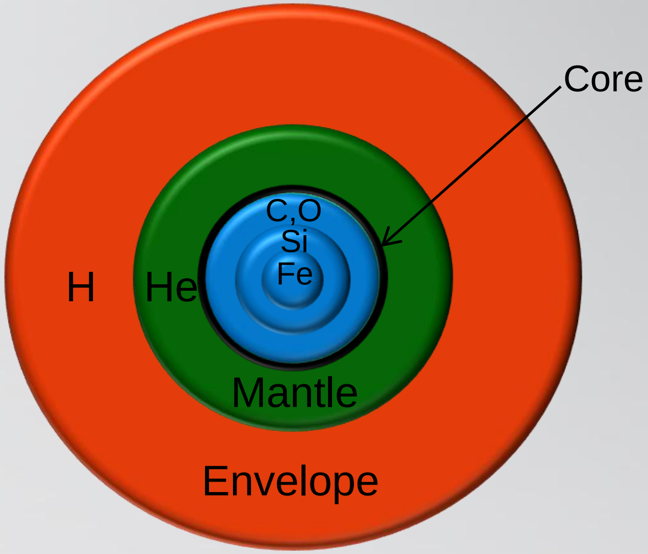
Type 1A: Thermonuclear



- **Source of the elements up to Z ~ 26**
- **Data behind the accelerating universe and dark energy**

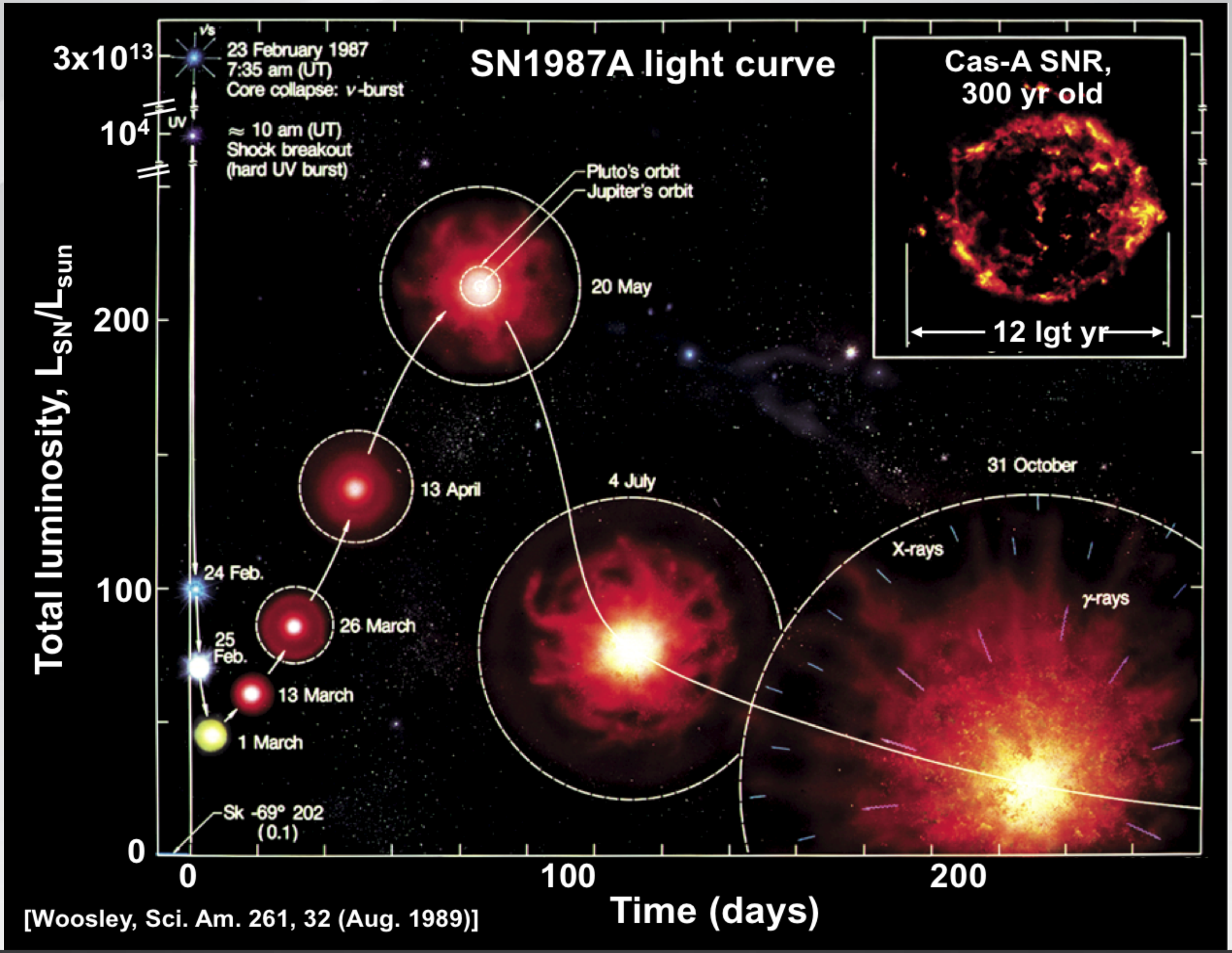
Type II: Core Collapse

Fe core in massive star collapses

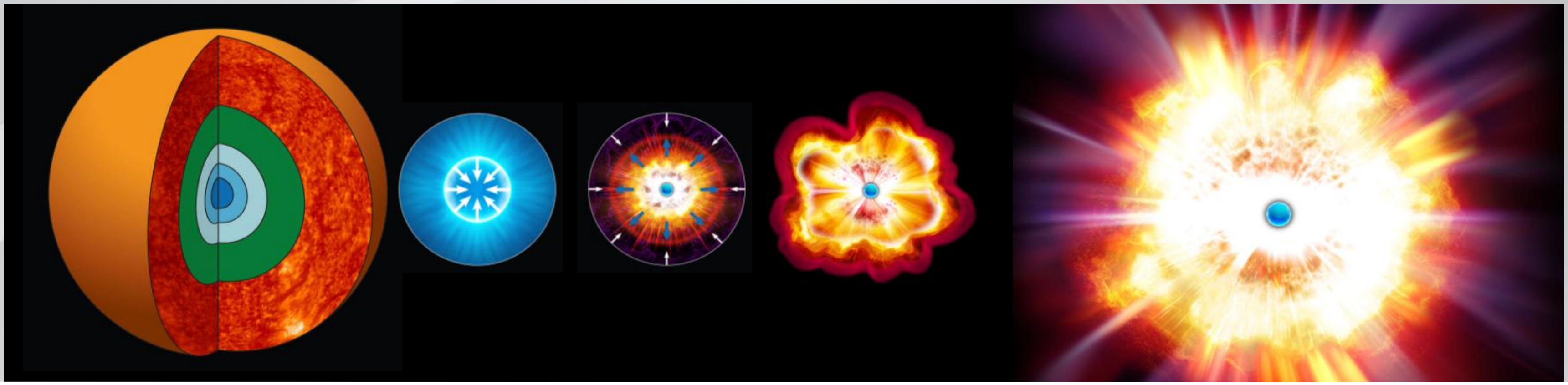


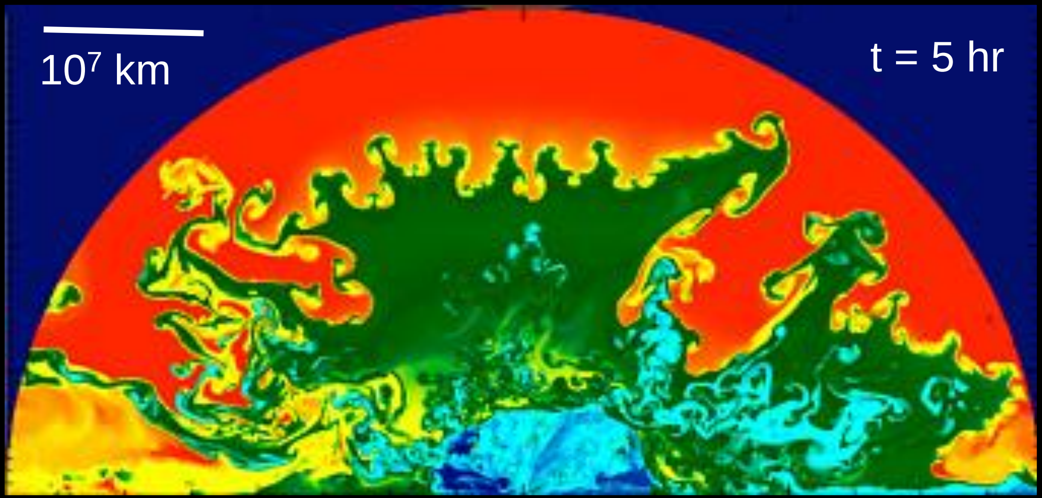
- **Source of the heavy elements, Z > 26**
- **Questions:**
  - **How are these elements made?**
  - **How are they ejected?**

Fe, Si, etc. are ejected from type II supernova explosions, leading to heavy element formation: how does this happen?



Type II supernovae result from the death of a massive star



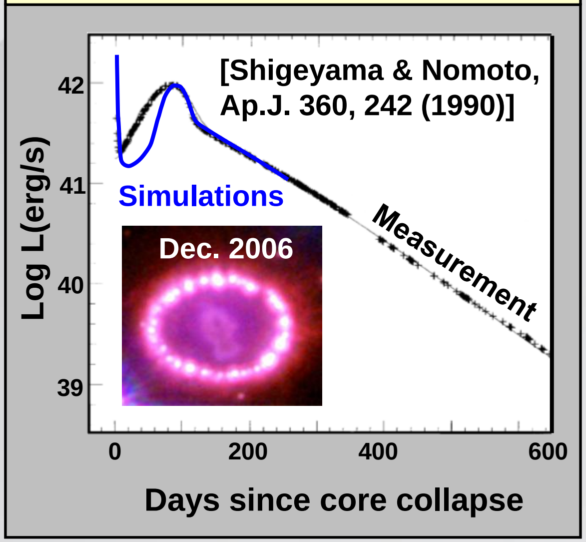


Turbulence mixes core (blue) into the overlying He mantle (green) and H envelope (red). Some fraction of the core, carrying the synthesized heavy elements, gets ejected.

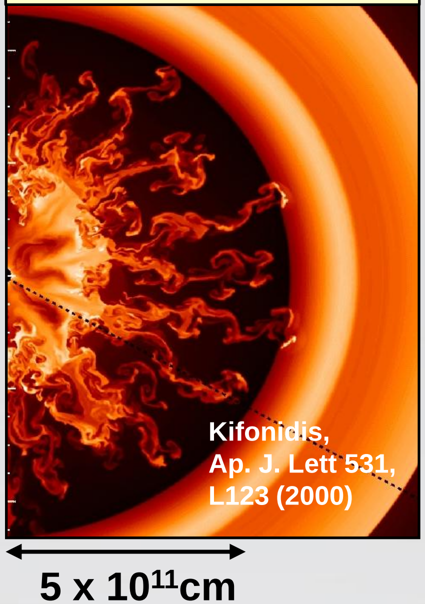
[Hillebrandt, Sci. Am., 43 (Oct. 2006)]

Simulations with low degree of hydrodynamic mixing do not agree with measurements

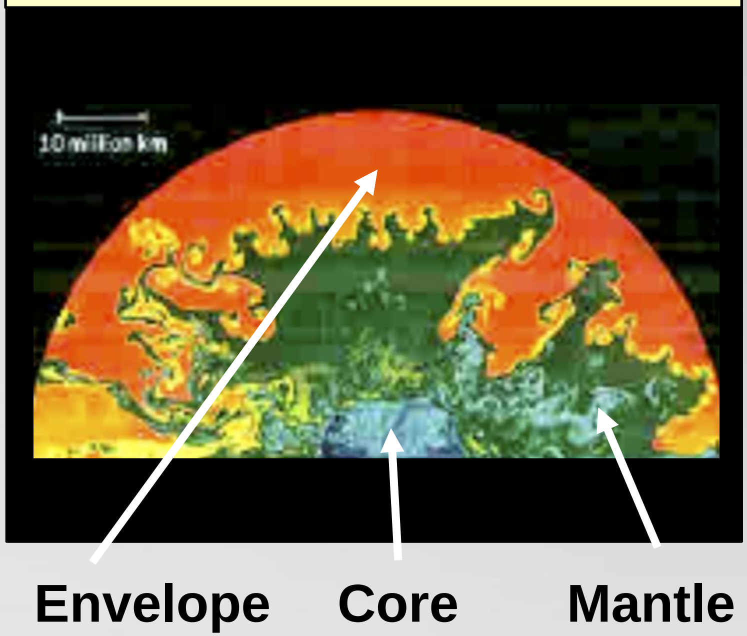
SN1987A measured light curve does not match low-mix simulation



Type II supernova simulation



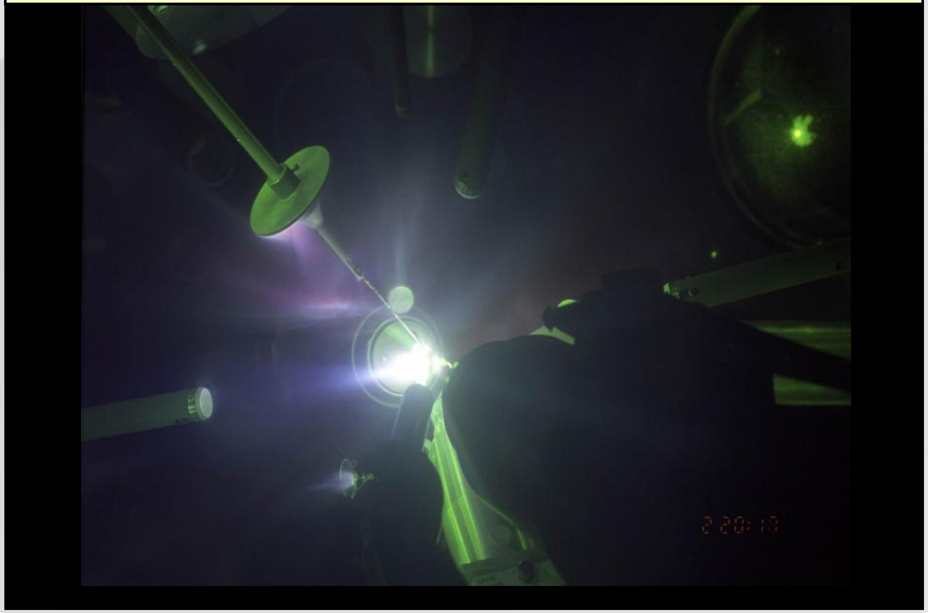
Simulation at t=5 hours, showing mixing of core, mantle, envelope



- Does He shell breakup allow core spikes to escape?
- Are differences in 3D vs 2D spike velocities important?
- How do 3D perturbations on multiple interfaces interact?
- How does the initial perturbation spectrum affect the late-time evolution?

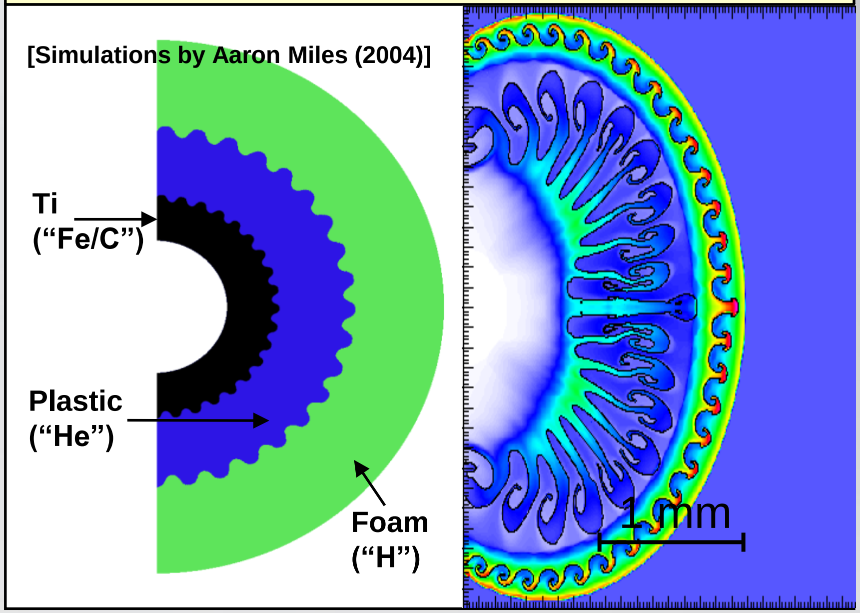
NIF has sufficient energy to test multi-interface simulations of core-collapse supernovae turbulent hydrodynamics

OMEGA experiments at University of Rochester Laboratory for Laser Energetics- proof of principle

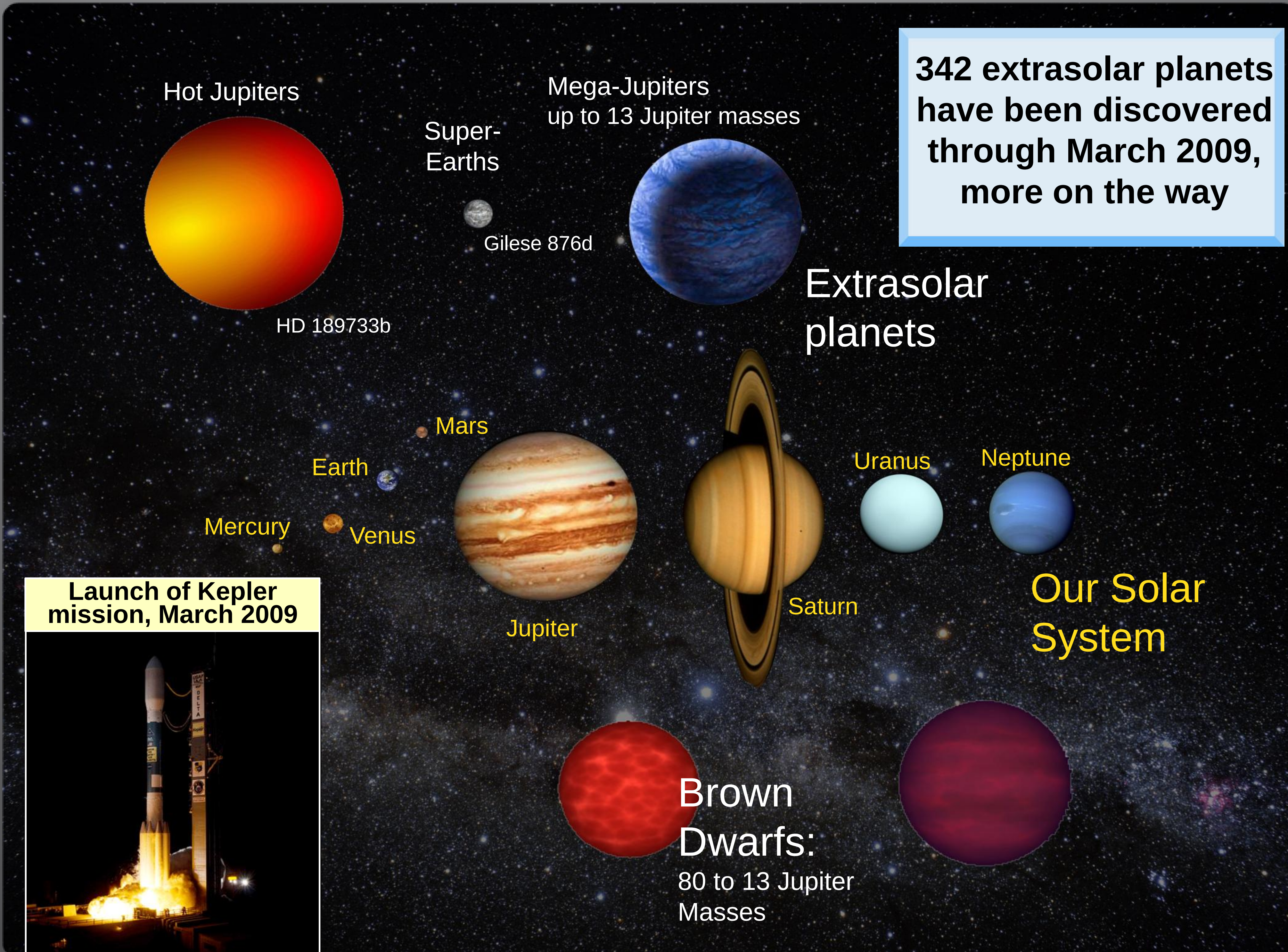


[Courtesy of Paul Drake et al.]

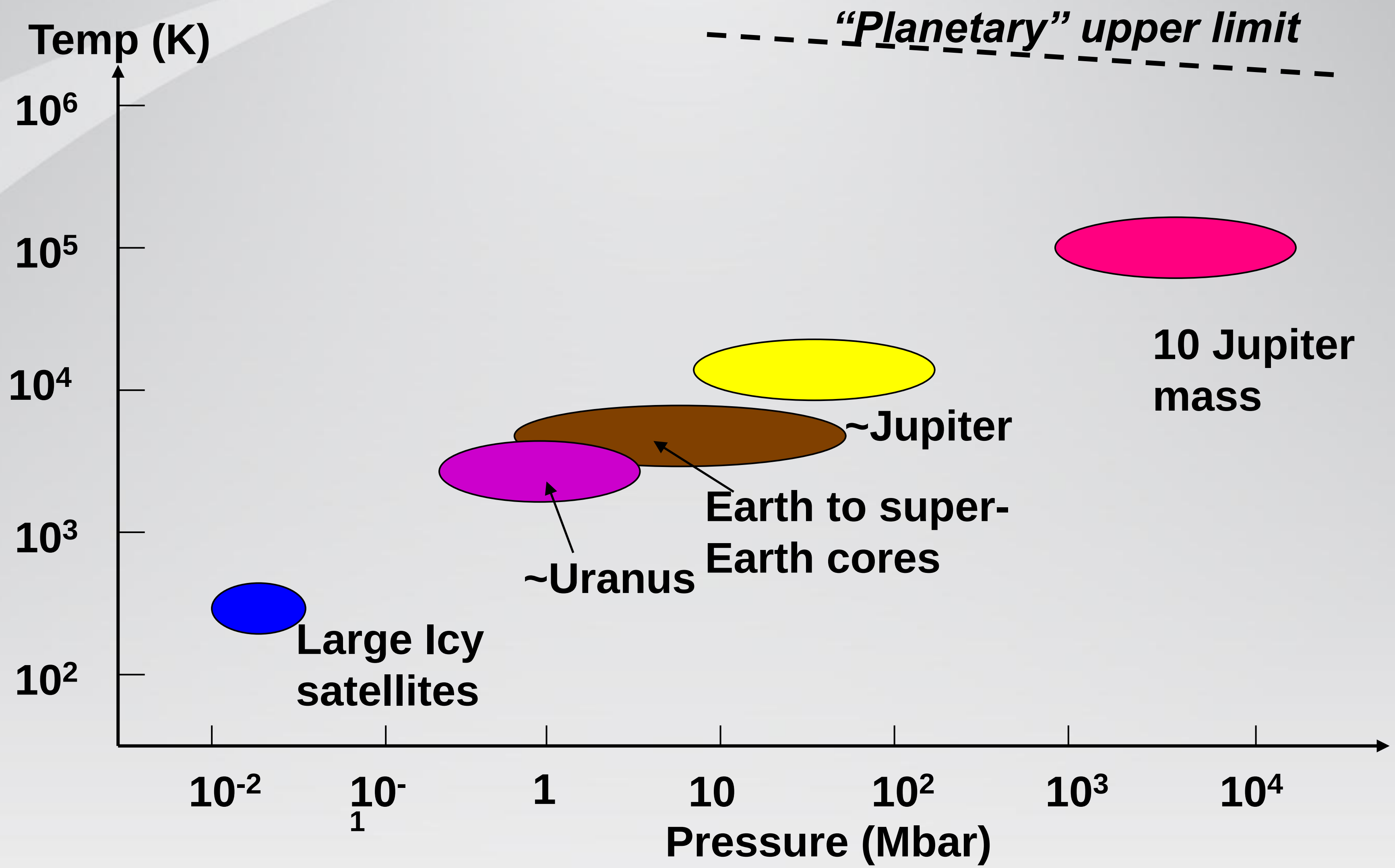
NIF hemisphere target and simulation- sufficient energy for multi-interface, diverging, scaled SN experiment



NIF experiments are planned to start in 2011-2012

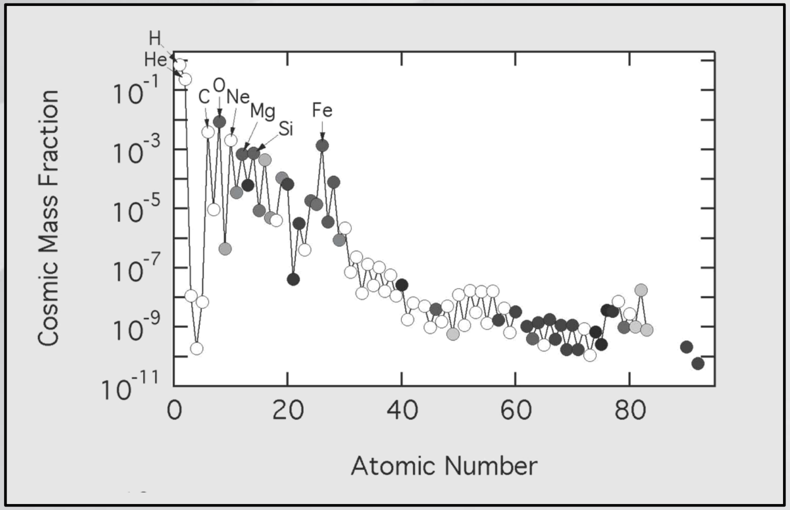

342 extrasolar planets have been discovered through March 2009, more on the way
Hot Jupiters
HD 189733b
Super-Earths
Gilese 876d
Mega-Jupiters up to 13 Jupiter masses
Extrasolar planets
Mars
Earth
Mercury
Venus
Jupiter
Saturn
Uranus
Neptune
Our Solar System
Launch of Kepler mission, March 2009
Brown Dwarfs:
80 to 13 Jupiter Masses

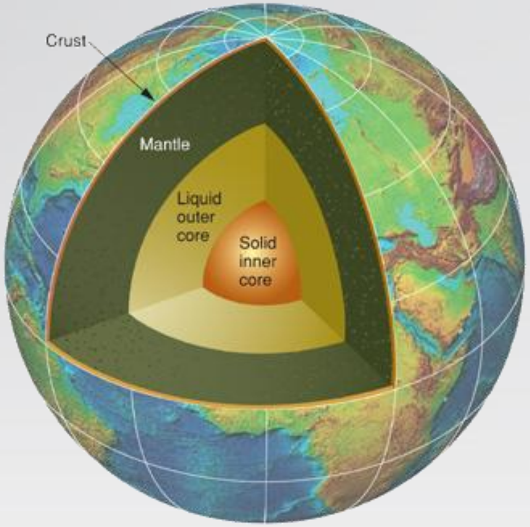
Understanding planetary structure requires knowledge of the Equation of State (EOS) at extreme conditions

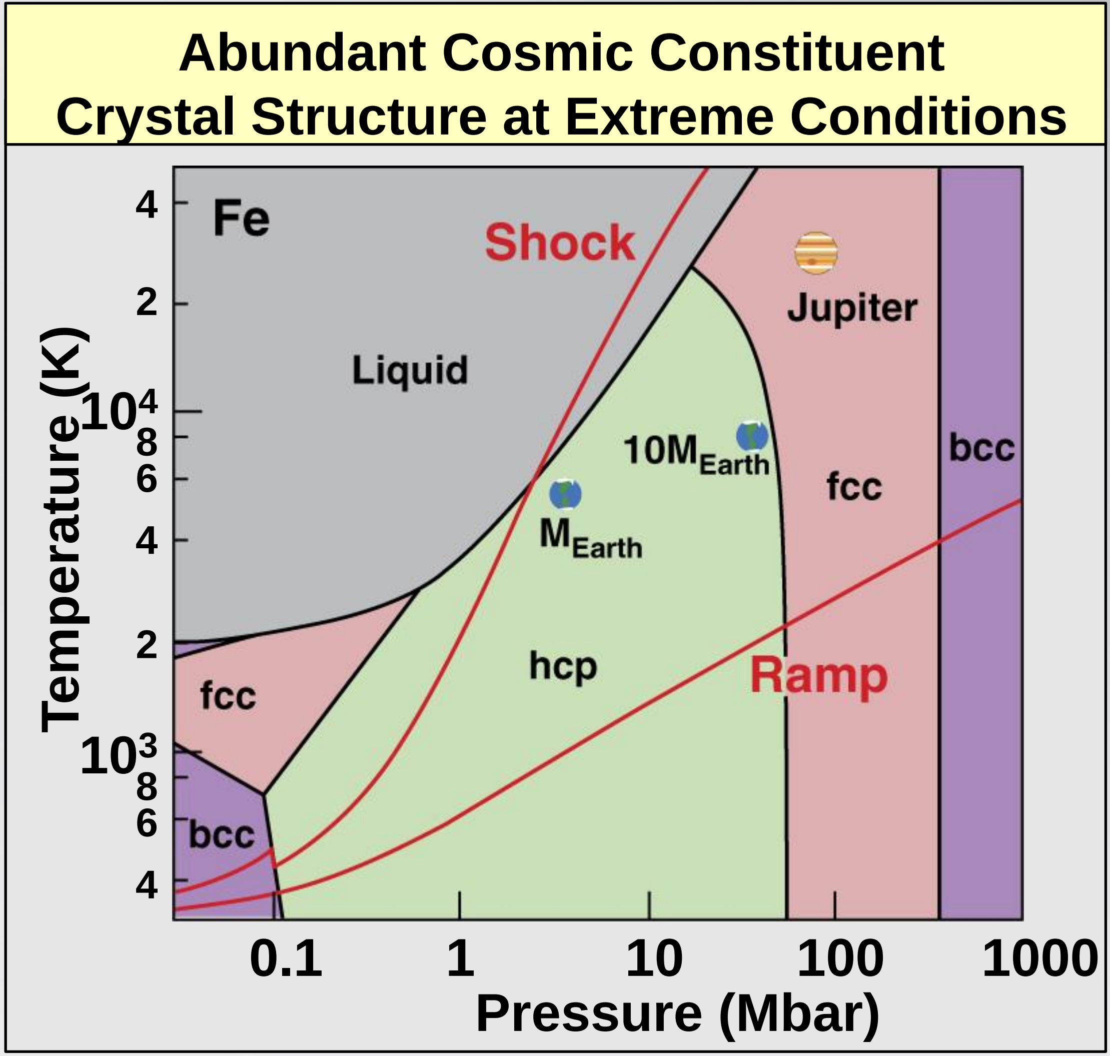


D. Stevenson

NIF can produce pressures exceeding 1 Gbar, allowing exploration of entirely new regimes

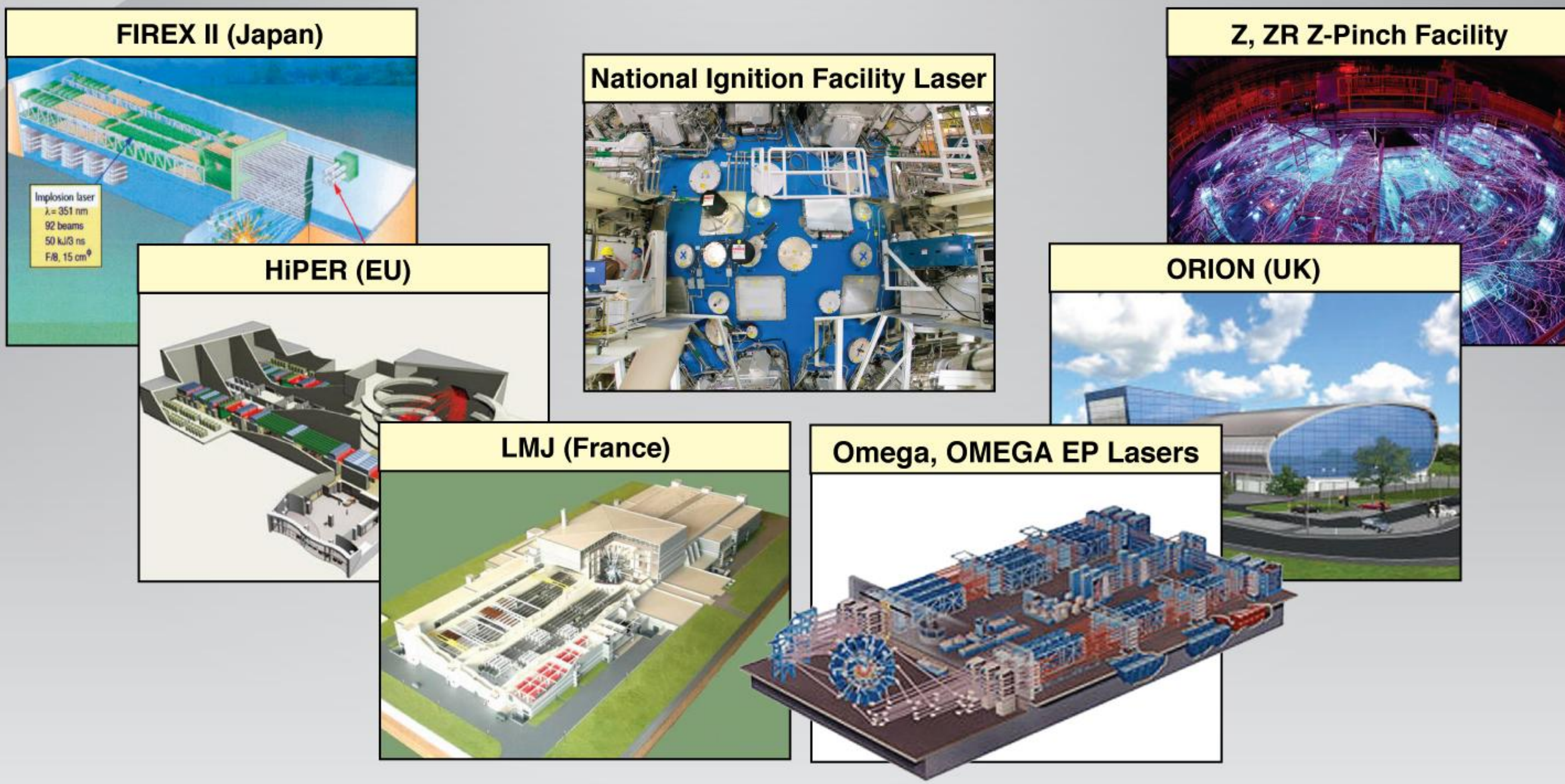






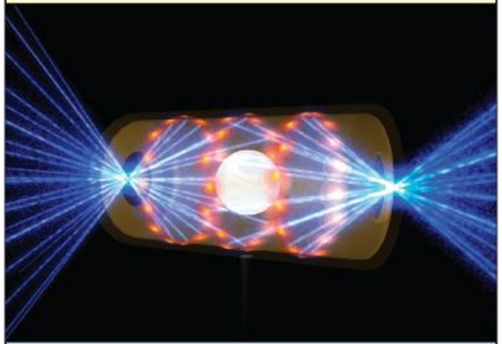
Stixrude, 2008

NIF is an integral part of a growing community of large-scale HED facilities world-wide



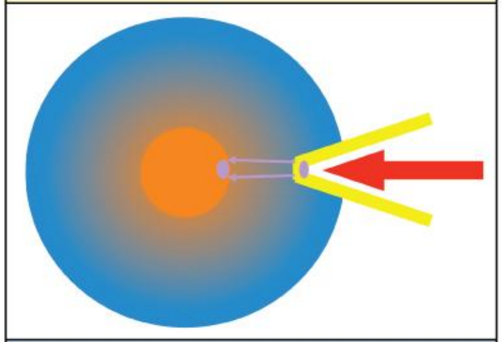
Growing these NIF user communities and associated funding are key to establishing NIF as a National User Facility

NIC



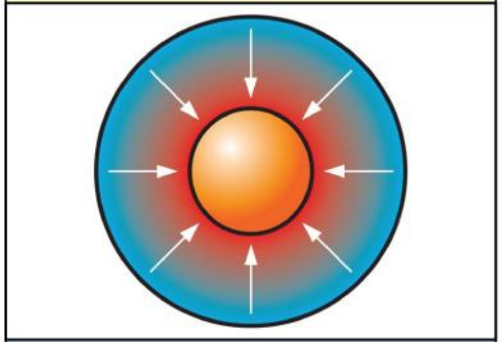
Mature, national lab and university scientists

Advanced fusion and IFE



Lab/university scientists

Weapons science



Primarily laboratory staff

Fundamental Science

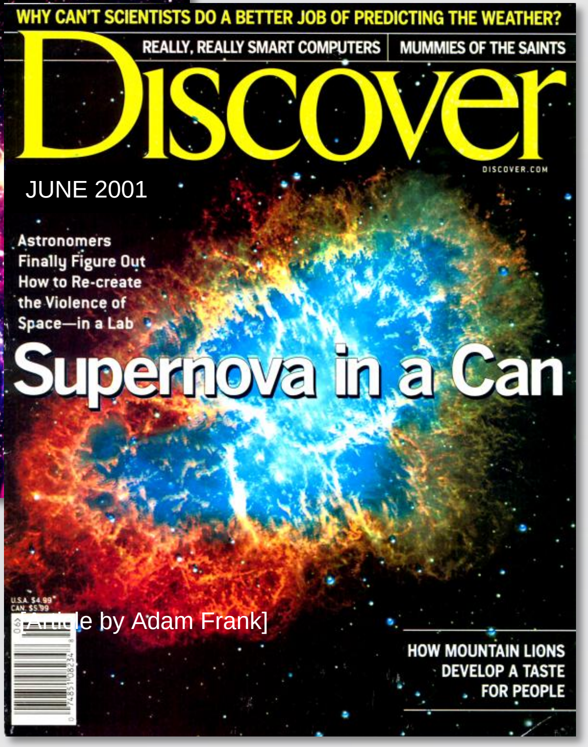
University and lab scientists

Global Security

DTRA, MDA, DHS, nonproliferation…

NIF-0309-16178r2
01CK/mfm

Steady growing interest in the popular press



Building NIF has been a challenging and exciting journey

NIF's Conceptual Design Report was issued in March, 1994

The National Ignition Facility:

Exploring Matter Under Extreme Conditions

Edward I. Moses
Principal Associate Director, NIF & PS

Presented to: Plenary Talk Conference on Lasers and Electro-Optics (CLEO) and the International Quantum Electronics Conference (IQEC)

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