LLNL-PRES-463640

Status of Experiments on National Ignition Facility

Presented to

31st Annual Meeting and Symposium Fusion Energy: Focus on the Future

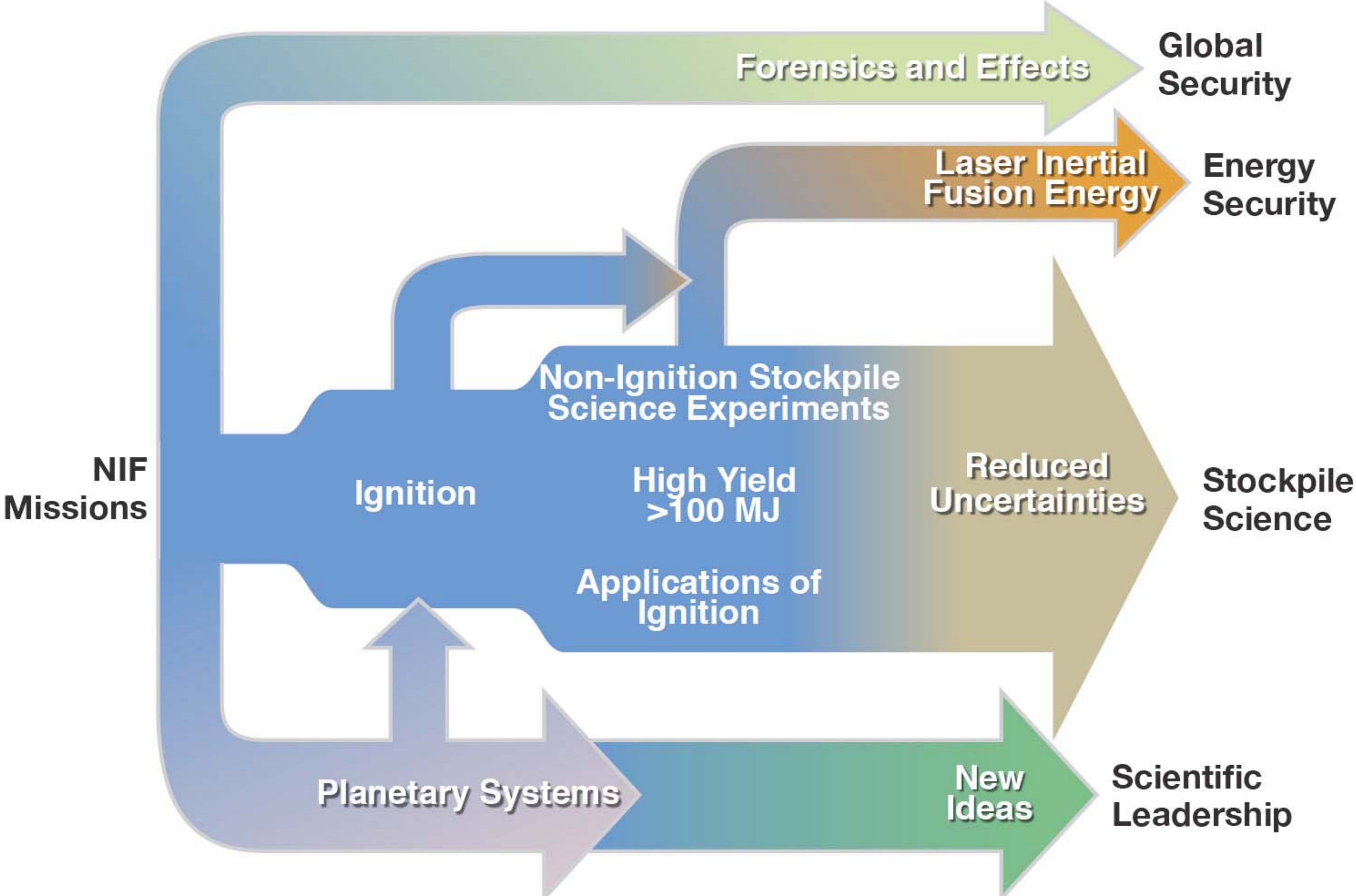
December 1, 2010

Edward I. Moses
Principal Associate Director
NIF & Photon Science

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


08EIM/ld · NIF-1110-20471s2

NIF missions

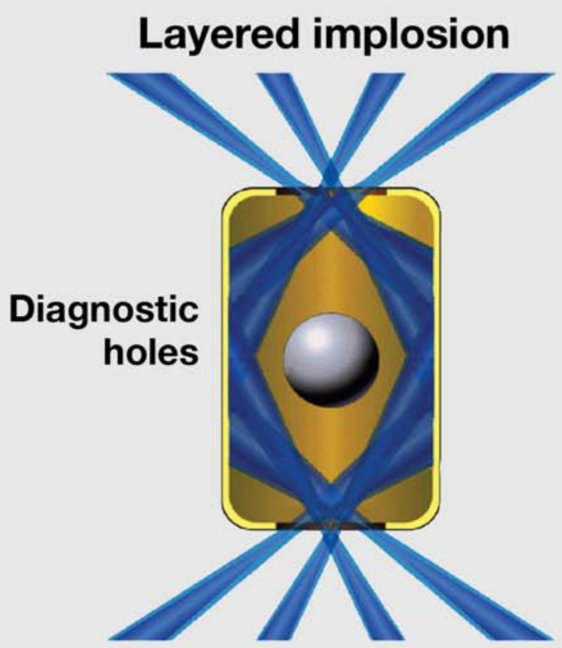


National Ignition Campaign

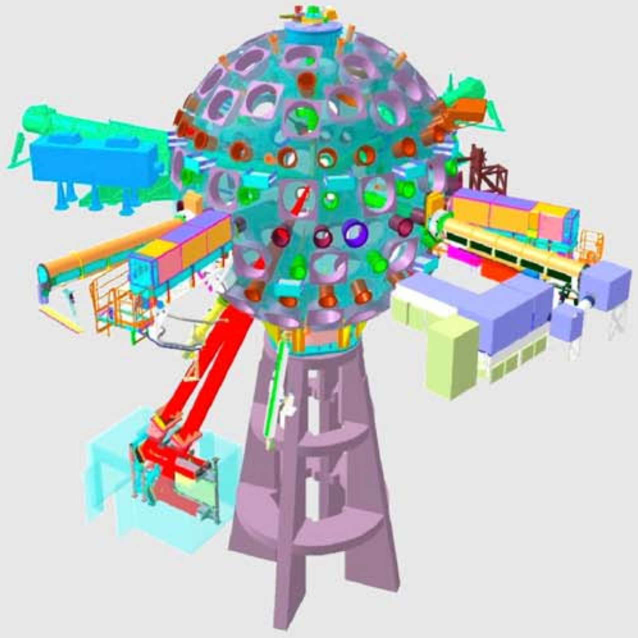
NNSA
National Nuclear Security Administration
GENERAL ATOMICS
UR LLE
Lawrence Livermore National Laboratory
Los Alamos NATIONAL LABORATORY
Sandia National Laboratories
MIT
AWE
cea
NSTec
BERKELEY LAB
Duke UNIVERSITY

National Ignition Campaign goals

Begin ignition experiments starting in FY2010



Develop an ignition platform for HED applications in FY2012



Transition NIF from project completion to routine facility operations by end of FY2012

NIC Summary

- **Following a successful 2009-2010 tuning campaign, we have demonstrated the world's first MJ hohlraum and associated modeling advances**
- **Initial hohlraum energetics experiments put us into the hohlraum temperature range for ignition experiments at 280-300 eV**
- **The laser, diagnostic, target fabrication and other infrastructure capabilities needed for the ignition campaign are now in place**
- **We have carried out the first THD cryo-layered implosion showing most aspects of system performance**
- **Ignition experiments in 2011–2012 lay the groundwork for target performance which meets the need for ignition applications and IFE requirements**

NIC

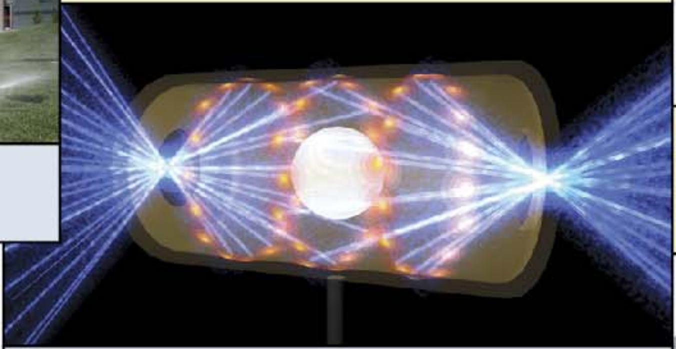
NIF is now capable of ignition experiments

This talk will focus on NIF, NIC and the path to laser inertial fusion energy

NIF Project

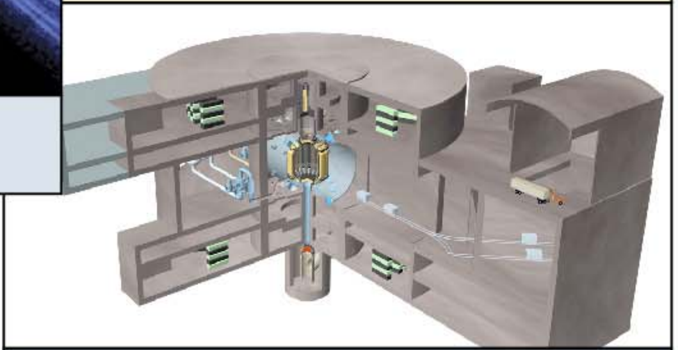
Operational

National Ignition Campaign



2006–2012

Laser Inertial Fusion Energy



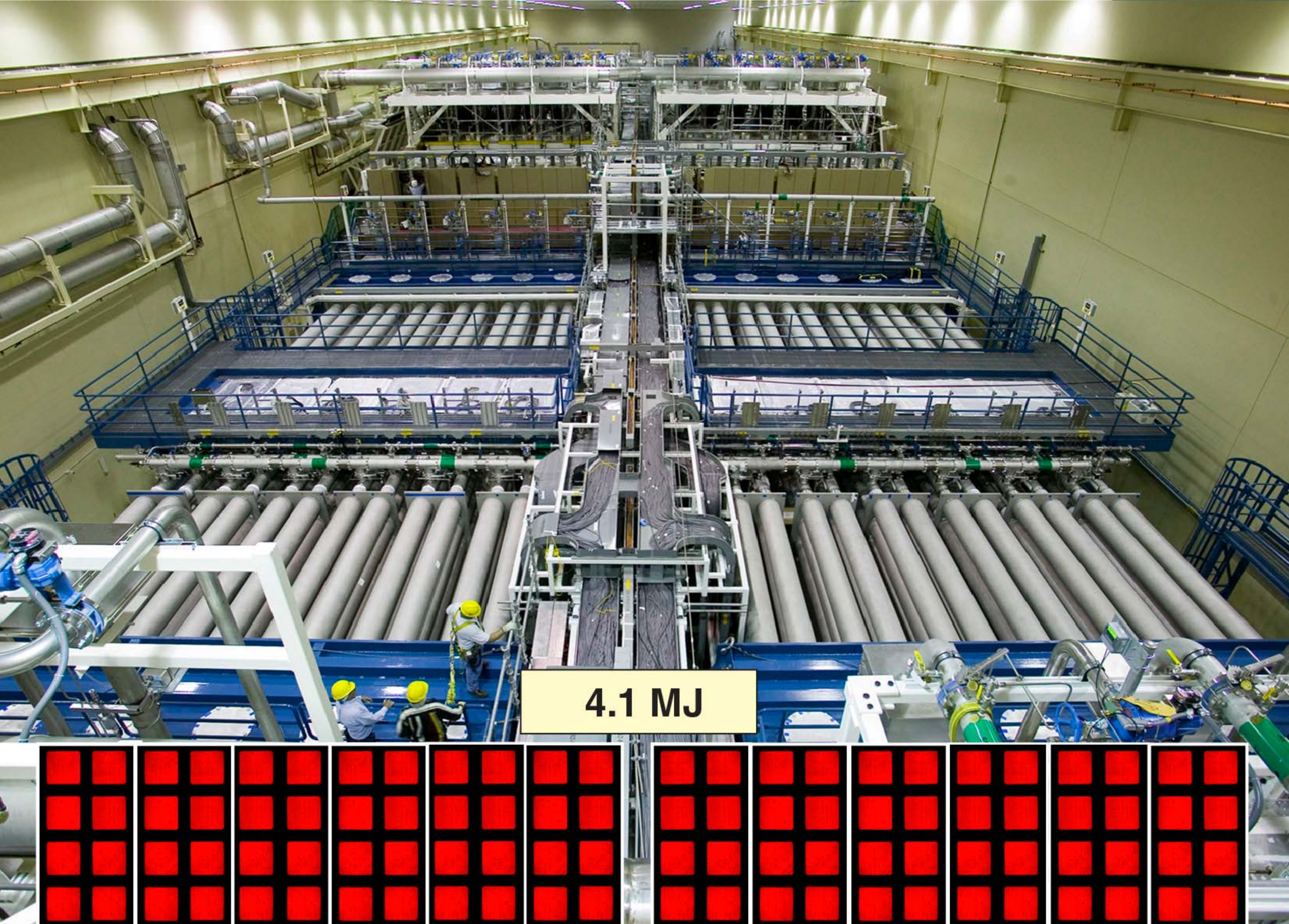
2010 and beyond

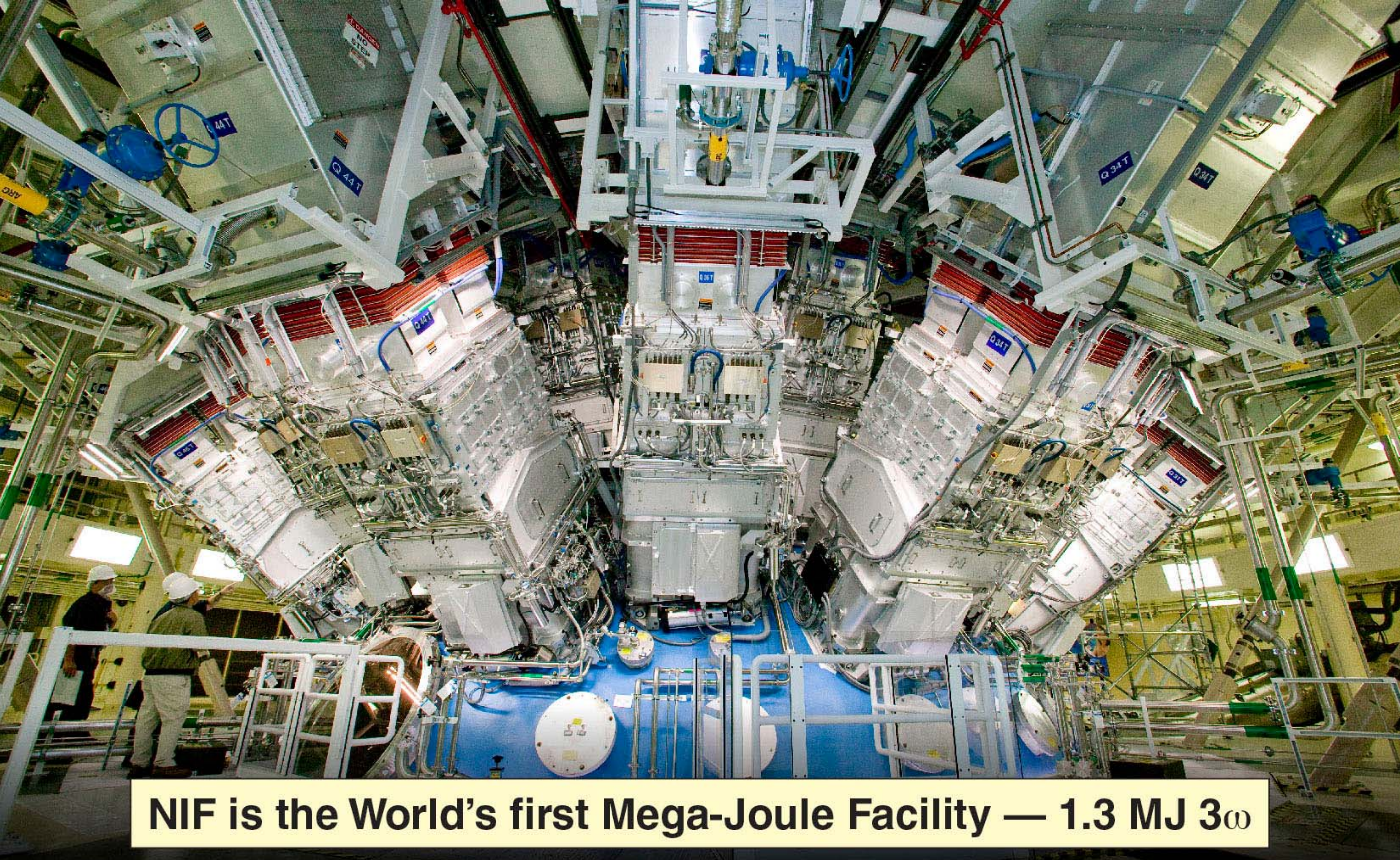
National Ignition Facility

- 1 Building, 5 Hectare
- 10 year construction complete
- 30 year operation

NIF concentrates all 192 laser beam energy into a mm^3 hohlraum

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

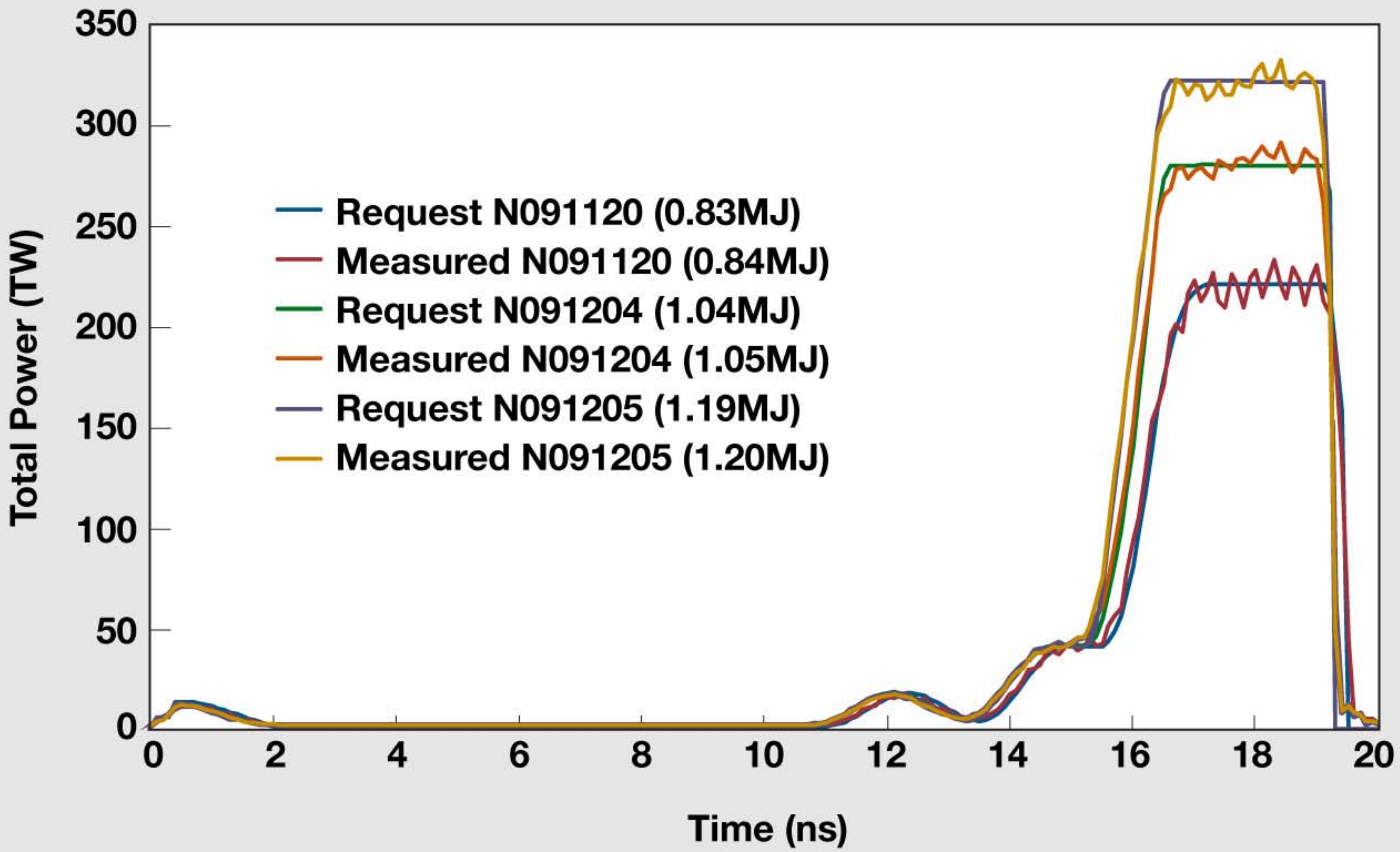

4.1 MJ



NIF is the World's first Mega-Joule Facility — 1.3 MJ 3ω

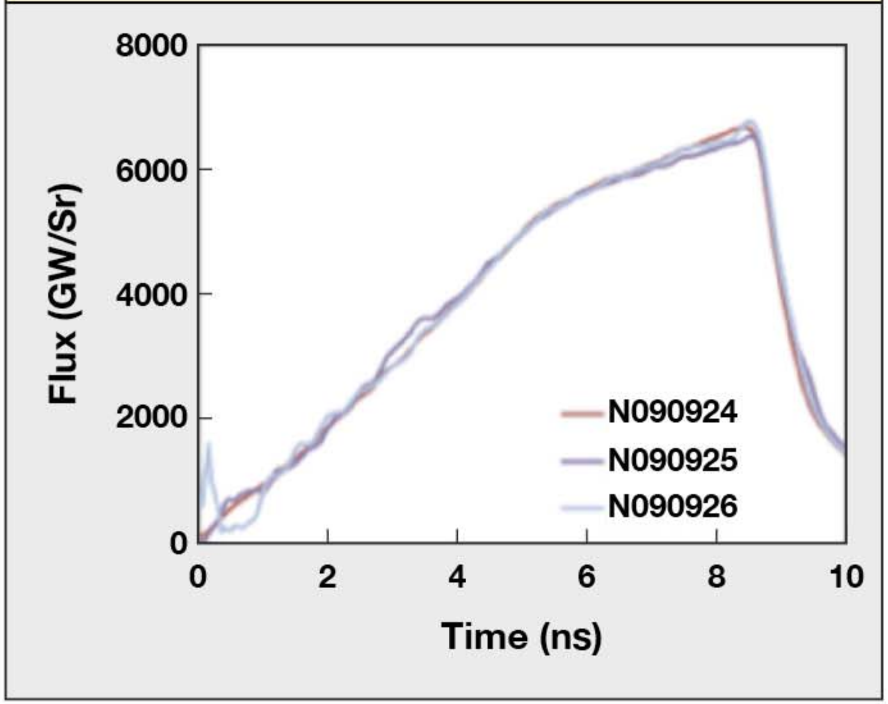
NIF laser has shown excellent ability to obtain the desired pulse shape and energy

Three ignition pulses of increasing energy between 0.84MJ and 1.2MJ

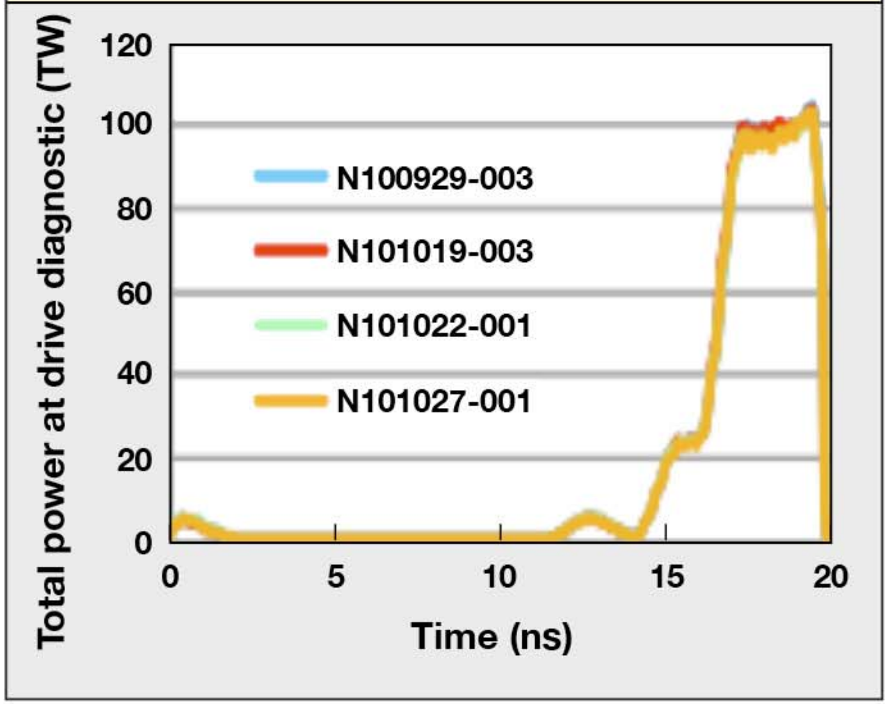


The NIF laser is highly reproducible

RAD Transport



Ignition



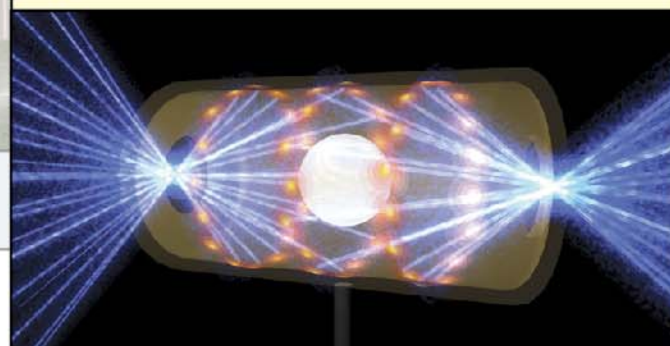
This capability enables the National Ignition Campaign tuning efforts

This talk will focus on NIF, NIC and the path to laser inertial fusion energy

NIF Project

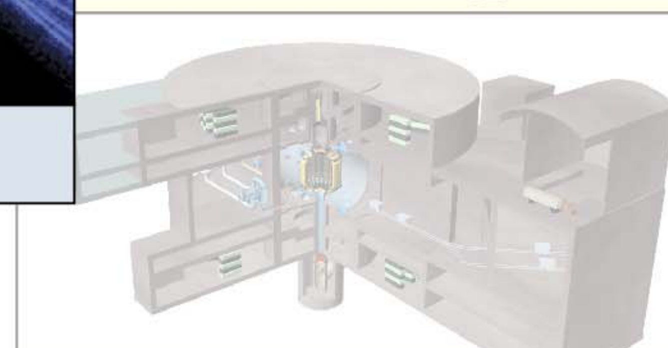
Operational

National
Ignition Campaign



2006–2012

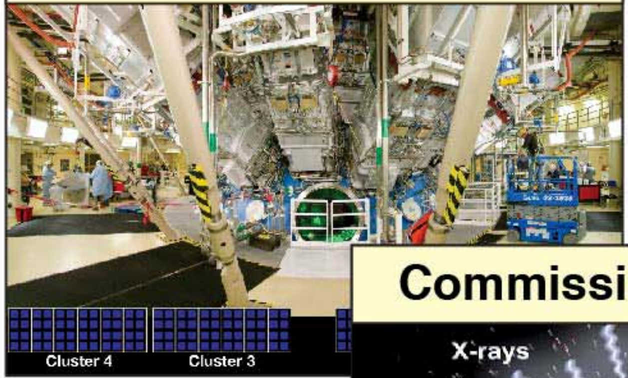
Laser Inertial
Fusion Energy



2010 and beyond

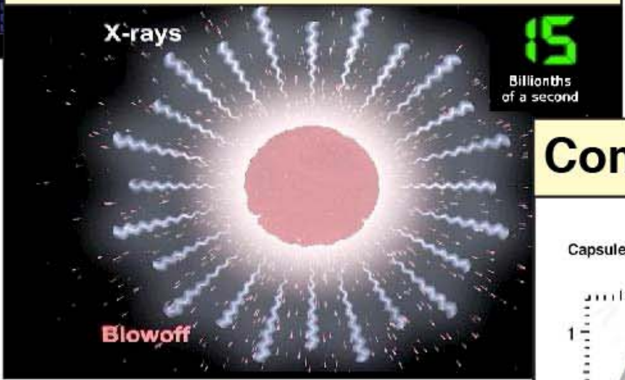
Four steps to ignition

Commission laser

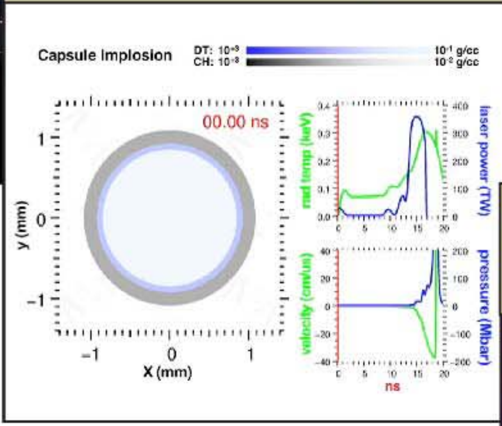


We are taking a systematic approach to learning and improving our enginering design to achieve ignition

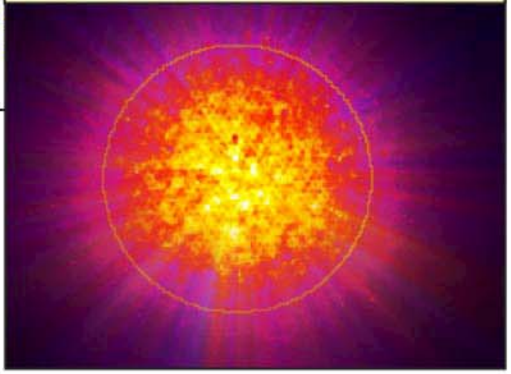
Commission hohlraum



Commission capsule



Commission layered target implosions

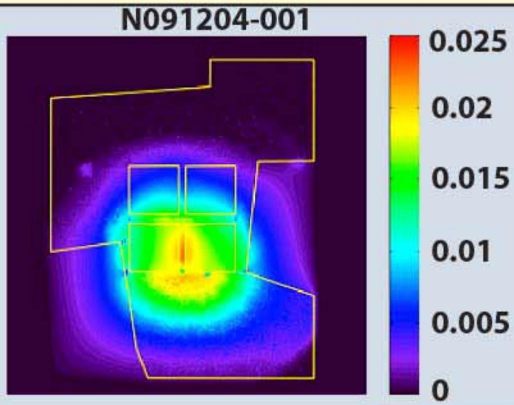


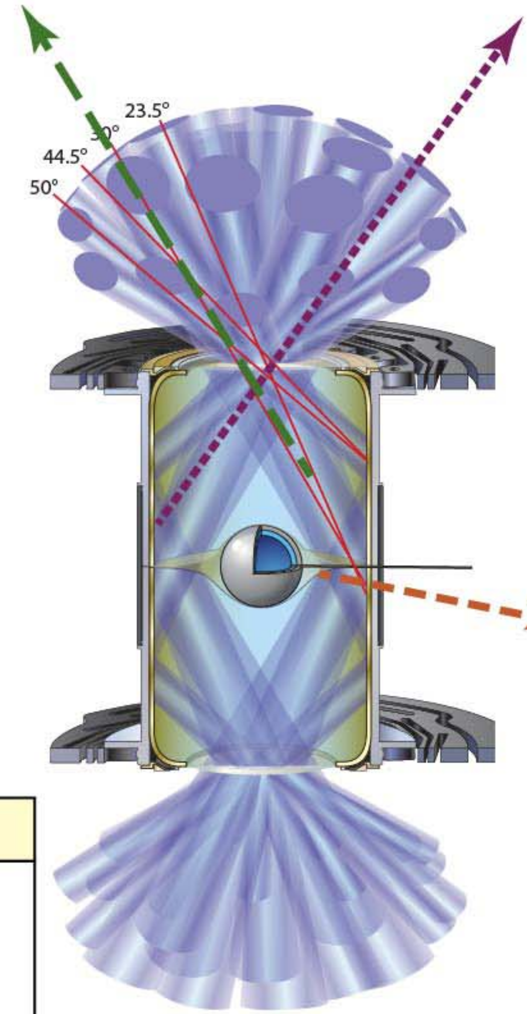
NIC Summary

- Following a successful 2009-2010 tuning campaign, we have demonstrated the world's first MJ hohlraum and associated modeling advances
- Initial hohlraum energetics experiments put us into the hohlraum temperature range for ignition experiments at 280-300 eV
- The laser, diagnostic, target fabrication and other infrastructure capabilities needed for the ignition campaign are now in place
- We have carried out the first THD cryo-layered implosion showing most aspects of system performance
- Ignition experiments in 2011–2012 lay the groundwork for target performance which meets the need for ignition applications and Inertial Fusion Energy requirements

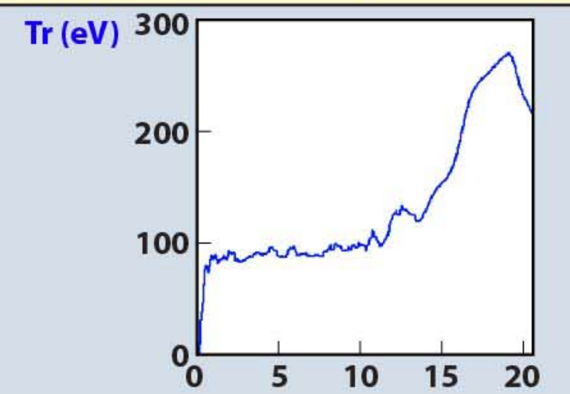
The fall CY09 experimental campaign demonstrated excellent Coupling, Drive, & Symmetry

Coupling: ~ 90% of incident laser stayed inside the hohlraum

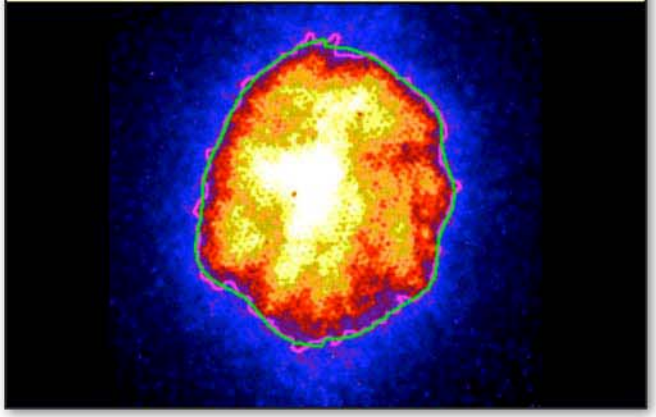




Drive: ~ 285 eV which is already quite close to that needed for ignition



Symmetry: To within ~ 10% of round, and tunable via Δλ

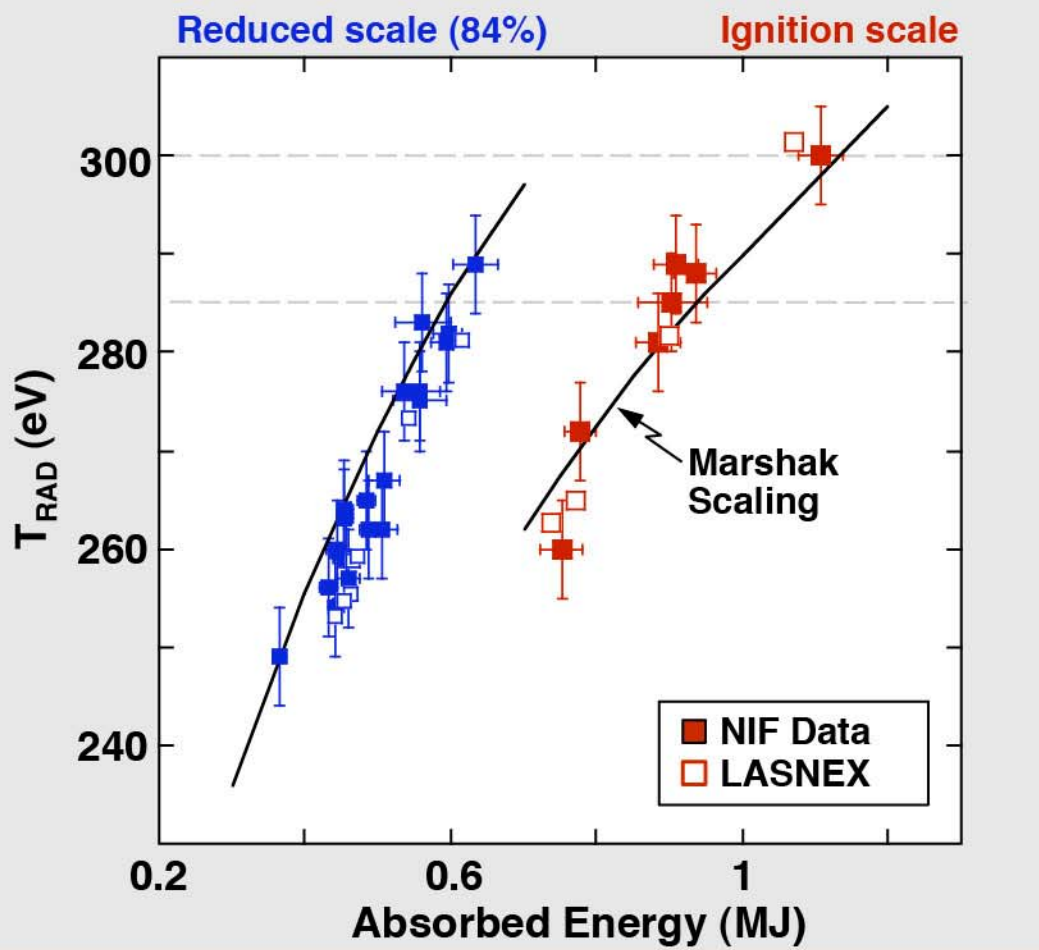


Peer Review Papers

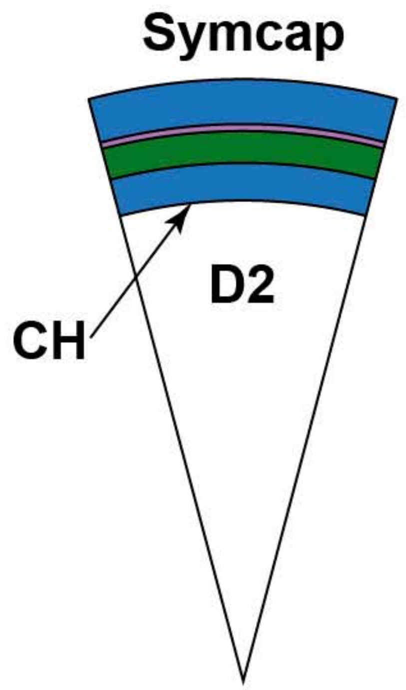
S. Glenzer et al., Science 327, 1228 (2010)
N. Meezan et. al. PoP 17, 056304 (2010)
P. Michel et. al. PoP 17, 056305 (2010)

The November 2nd experiment demonstrated ignition point design hohlraum temperatures of 300 eV

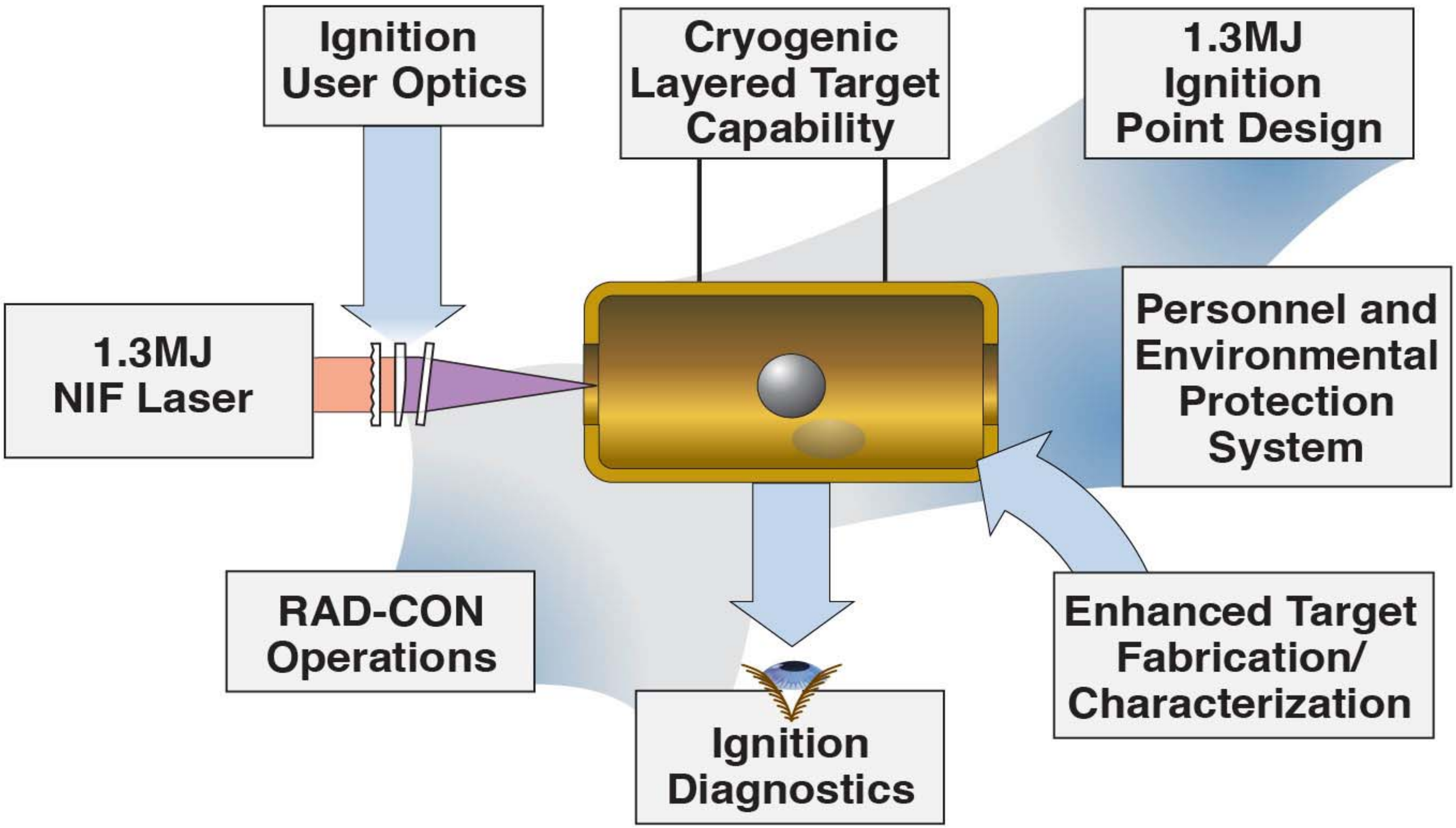
Fully cryogenic ignition scale hohlraums show 87 - 90% coupling at 1 – 1.3 MJ laser drive



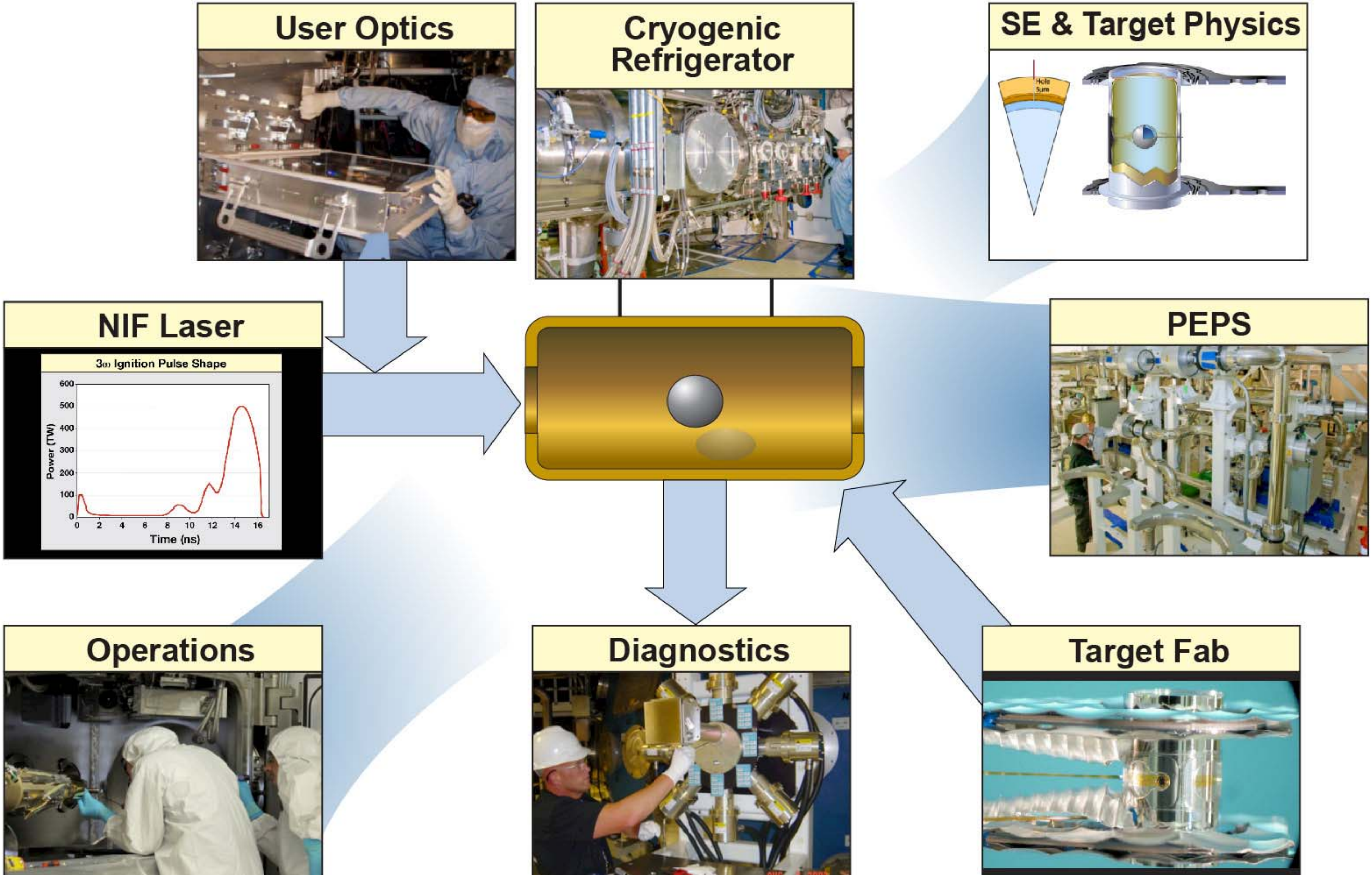
Shot taken on November 2, 2011



During December – August 2010 we added required functionality for yield campaigns



All the elements are in place, the "first integrated ignition experiments" was conducted on September 29, 2010



Shield Door Installation

Tritium processing

Major new ICCS Releases

Cryo Tarpos in NIF (May 2010)

NIF has over 36 diagnostic instruments developed through international collaborations

LLNL
- FABS,NBI
- Dante I & II
- VISAR
- DISC
- RAGS
- hGXI
- ARIANE
- DIXI
- NAD

NSTec
- Calibration
- NToF

LBNL
- Calibration
- Rad. Chem.

LLE
- NToF
- 4ω fidu system
- MRS, NADS
- SPBT
- HEXRS
- PSBT

AWE
- FFLEX

MIT
- MRS
- WRF
- PSBT

LANL
- GXD
- γ burn
- Rad. Chem. II
- n imaging

SNL
- SPIDER
- DISC
- NAD (Cu)
- NToF

Duke
- Calib.

CEA
- N imaging

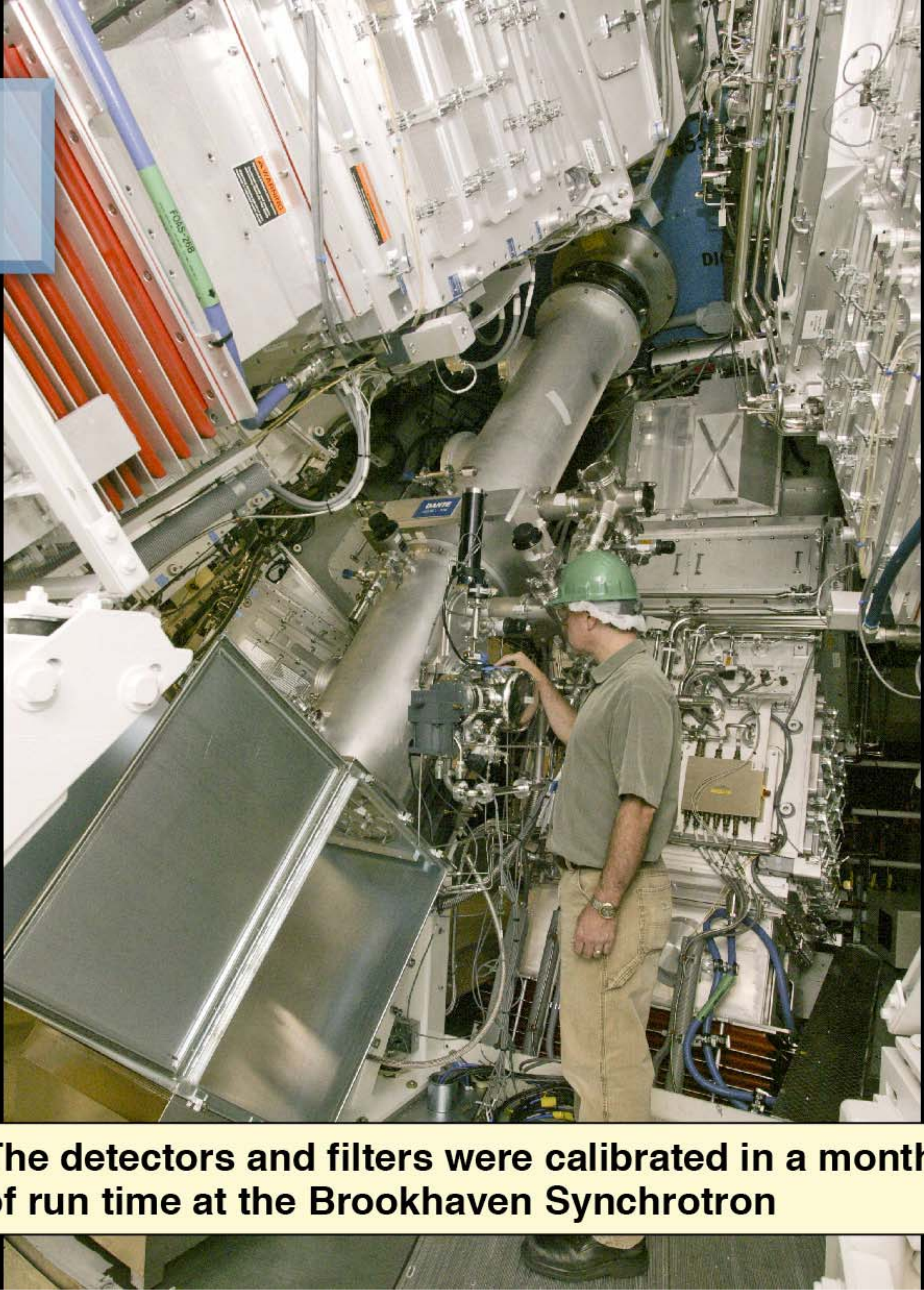
Opportunities with NIF diagnostics attract scientists

NToF*

* Neutron Time of Flight

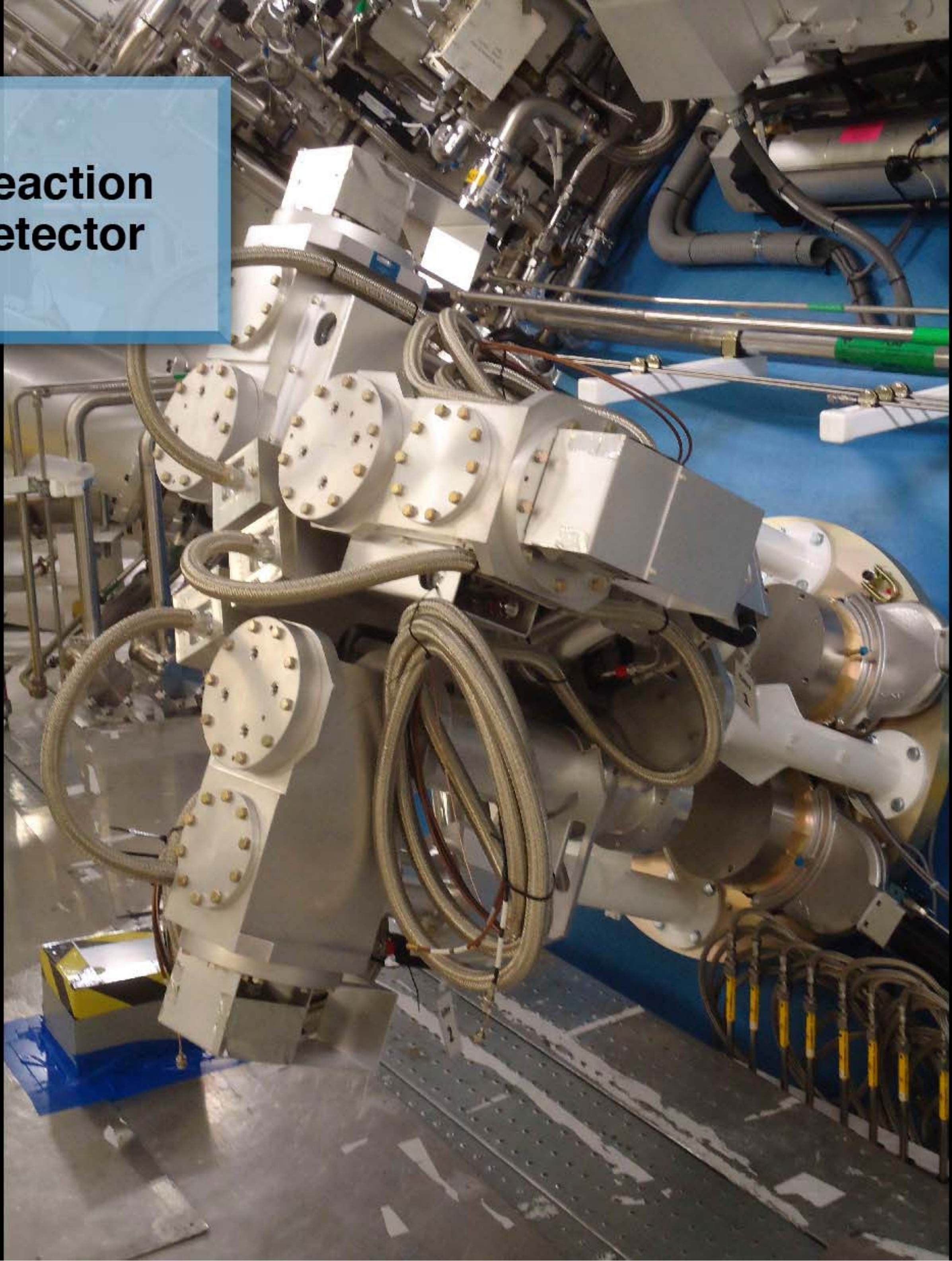

Magnetic
Recoil
Spectrometer
DANGER
100% TIE-OFF
BEYOND THIS
POINT
nTOF 4.5 (64,330)
DIAGNOSTIC WELL BOX,
DWB3
WARNING
CAUTION
SCAFFOLD
TAG

DANTE 1



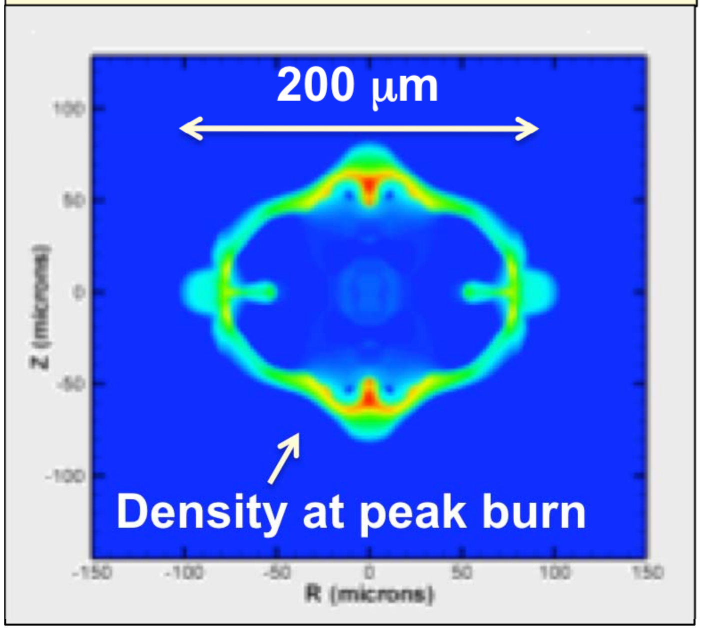
The detectors and filters were calibrated in a month of run time at the Brookhaven Synchrotron

Gamma Reaction History Detector

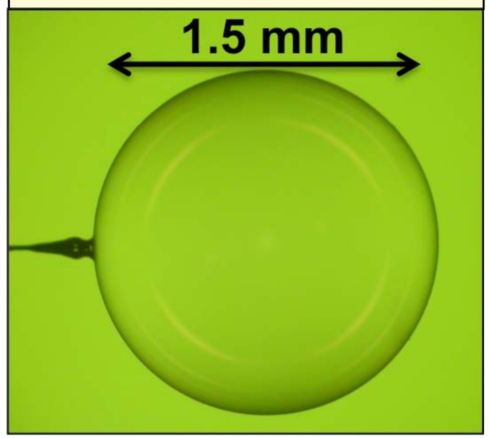


Three independent diagnostics measured 2.2 ± 0.2 x 1014 DT neutrons from an exploding pusher

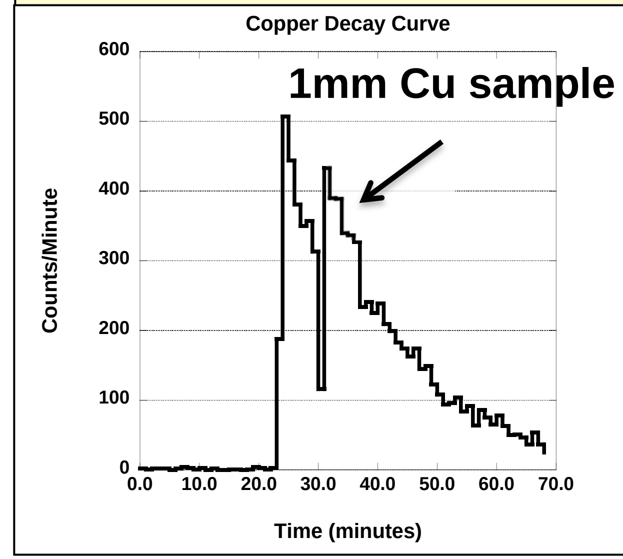
Design at LLE (122kJ, 2ns)



GA target, DT (50:50) filled at LLE

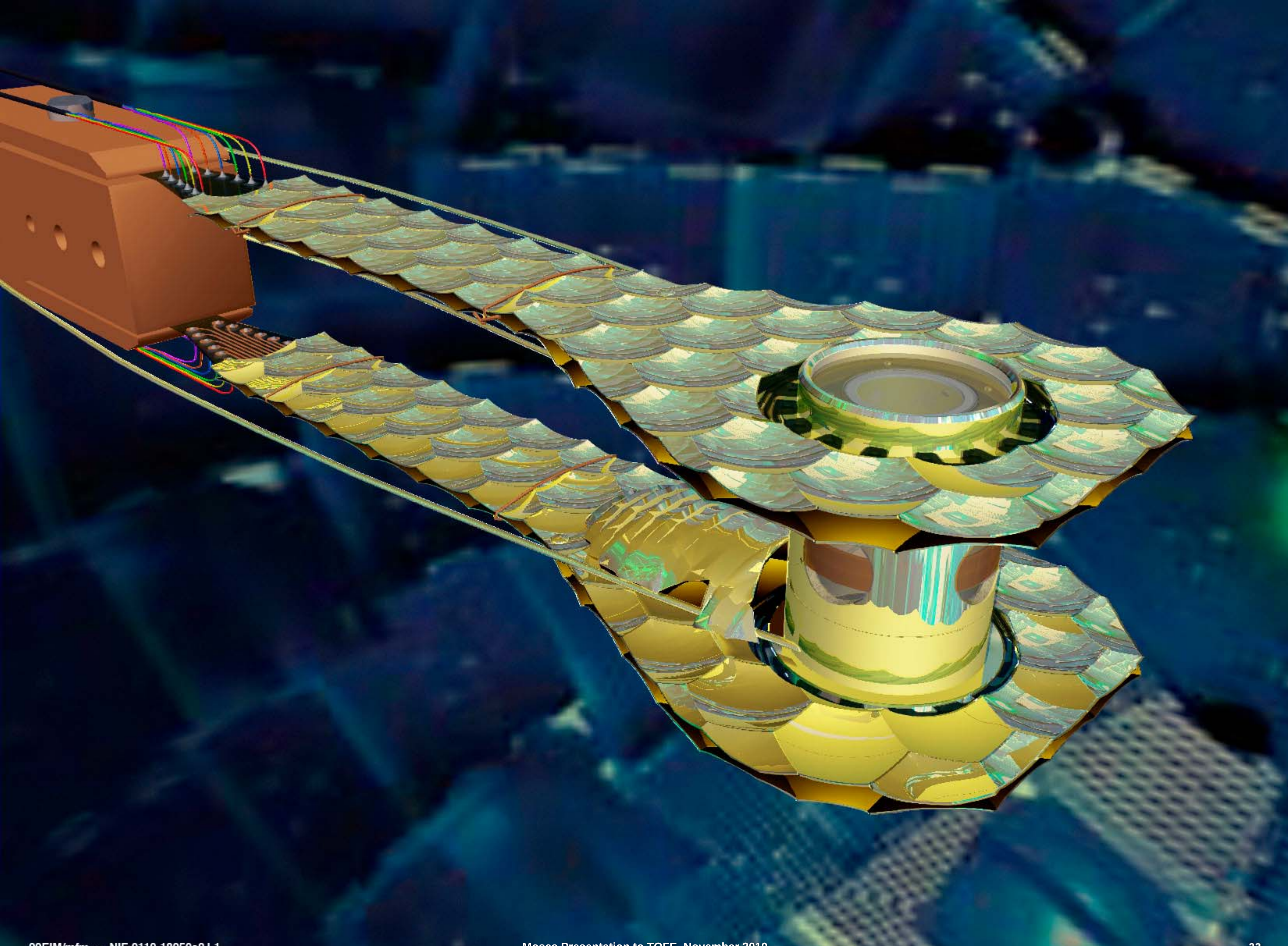


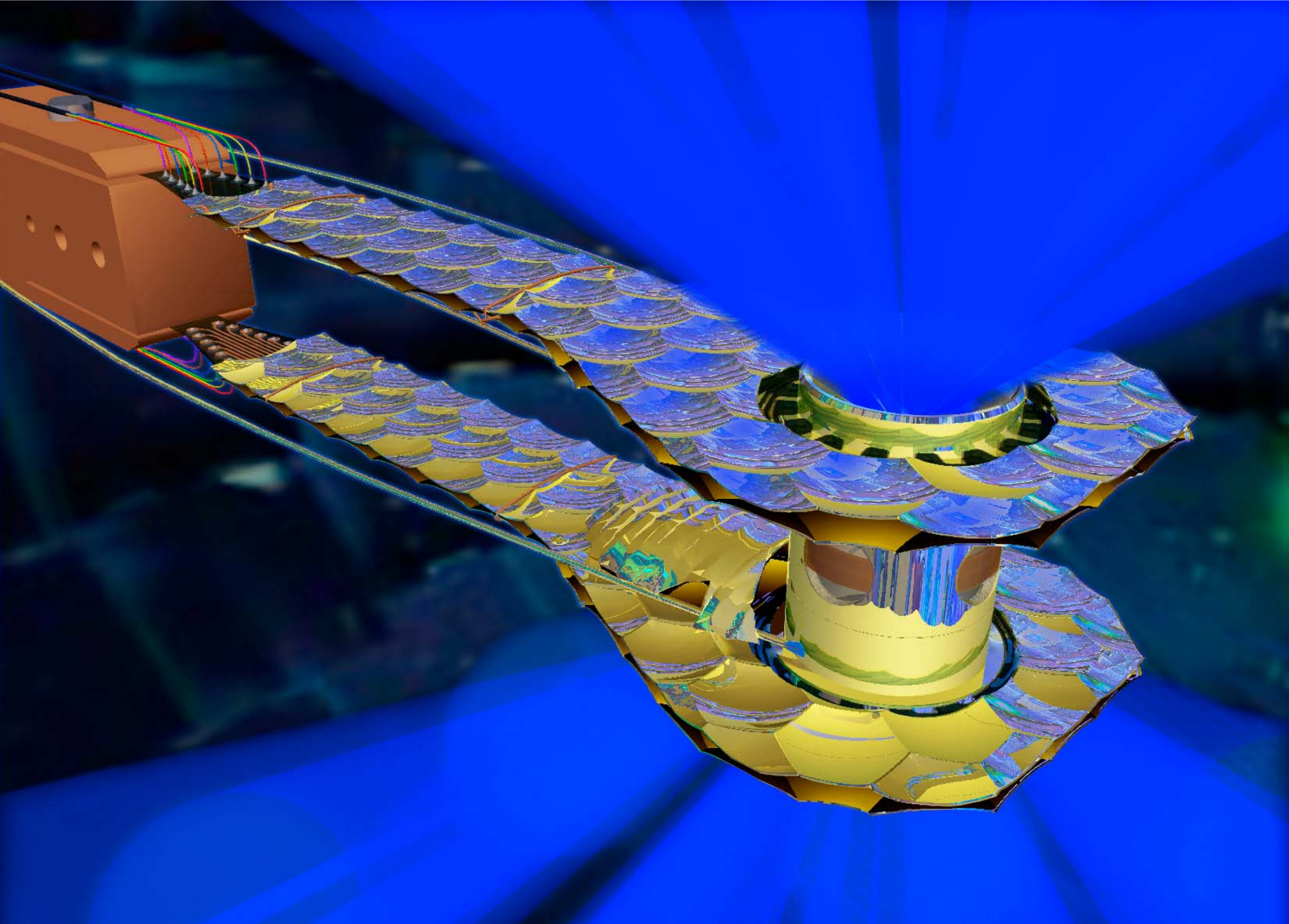
Copper activation

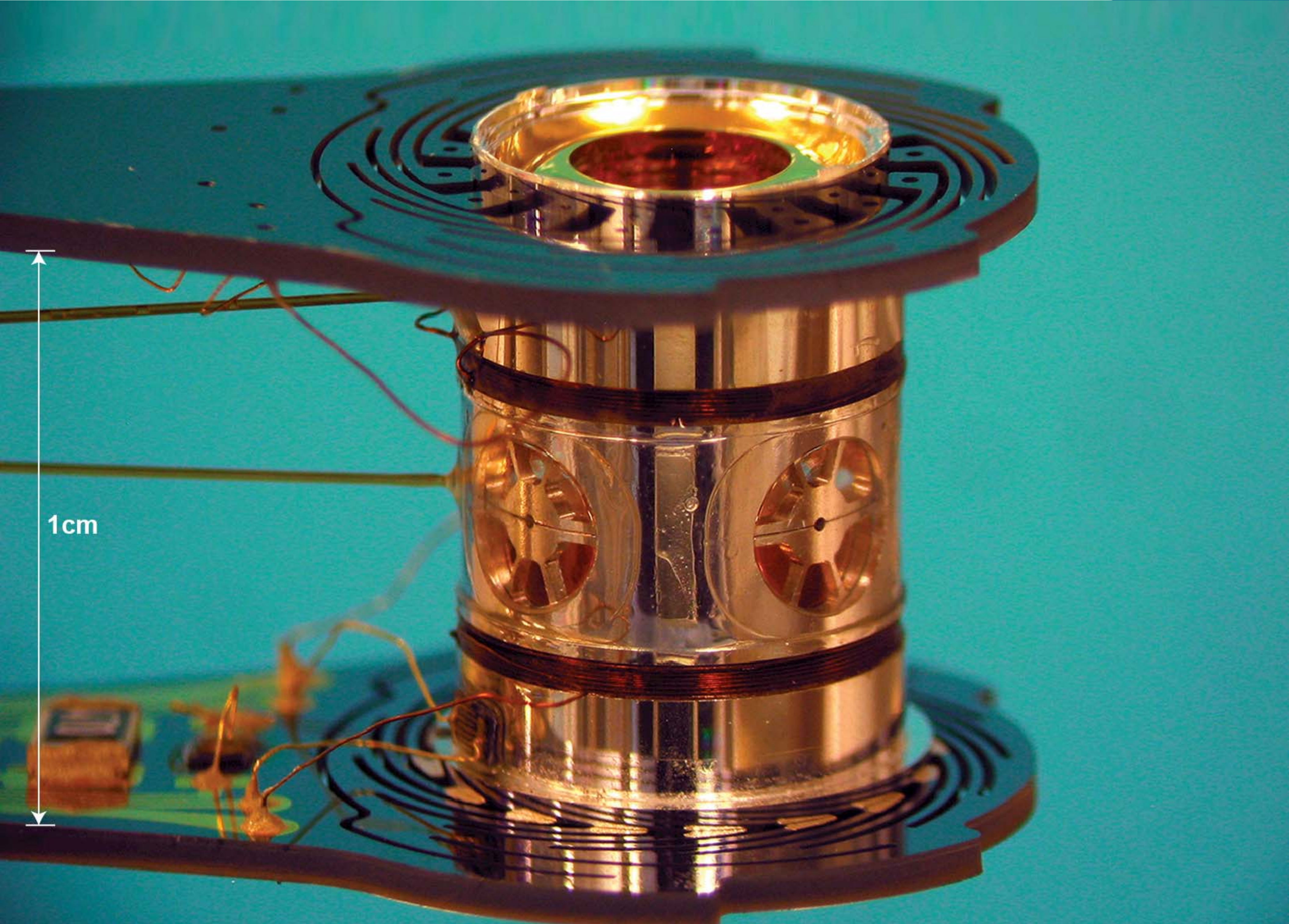


Observable	Simulations Pre Shot	Experiment (weighted mean) N1001030-002-999
Yield (Cu,Zr activation, MRS)	2-3e14	$2.2 \times 10^{14} \pm 0.2 \times 10^{14}$
Ion Temperature	11-12keV	11.7 ± 0.5 keV
Bang time	1.90 ± 0.2 ns	1.75 ± 0.15 ns

Advanced Radiographic Capability (ARC)

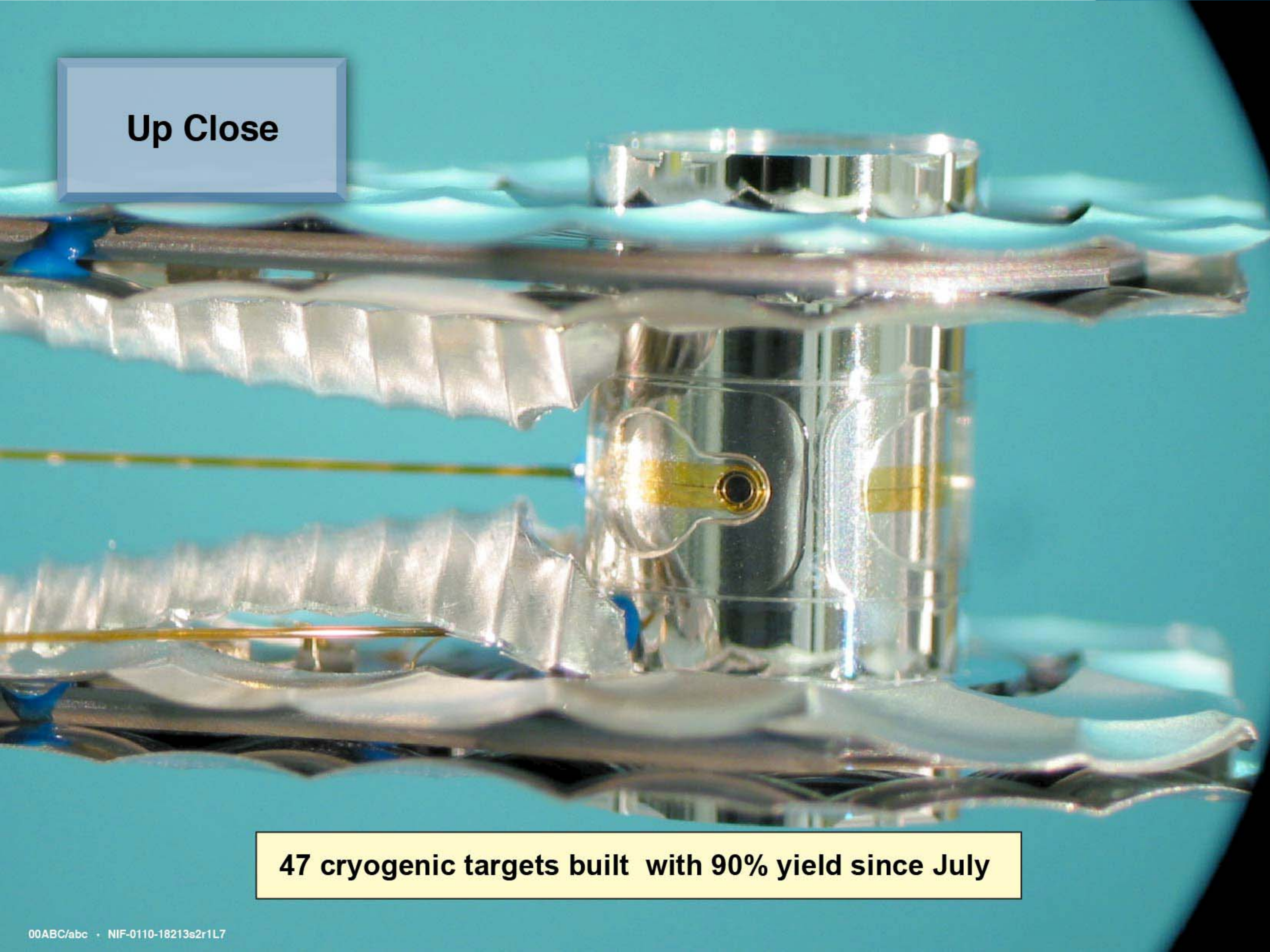






00ABC/lh · NIF-1110-20459s2

Up Close

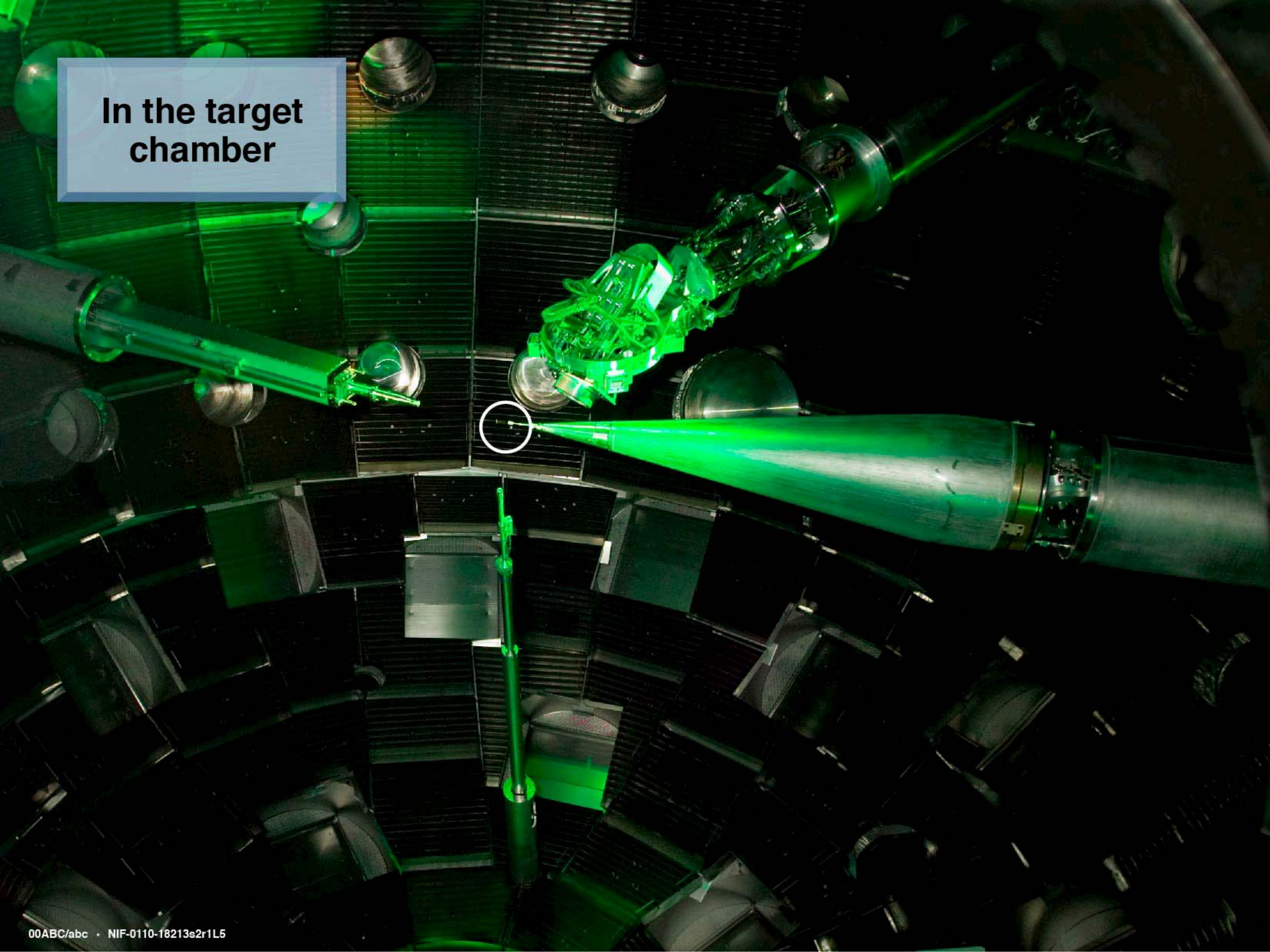


47 cryogenic targets built with 90% yield since July

On September 29, 2010 NIC conducted the first cryo-layered target experiment on NIF

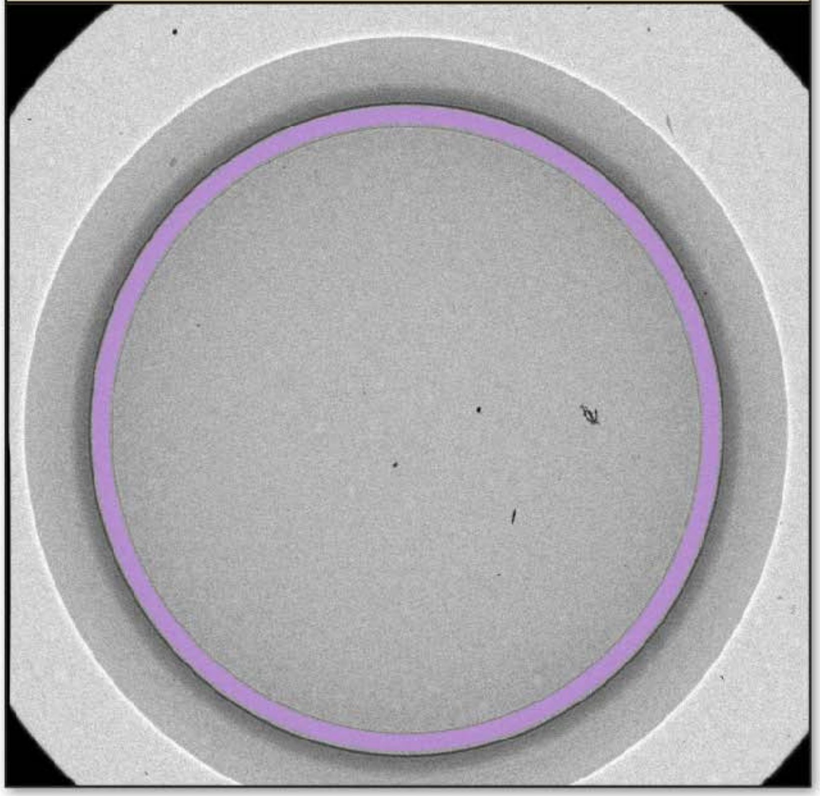
Target before the shot

In the target chamber



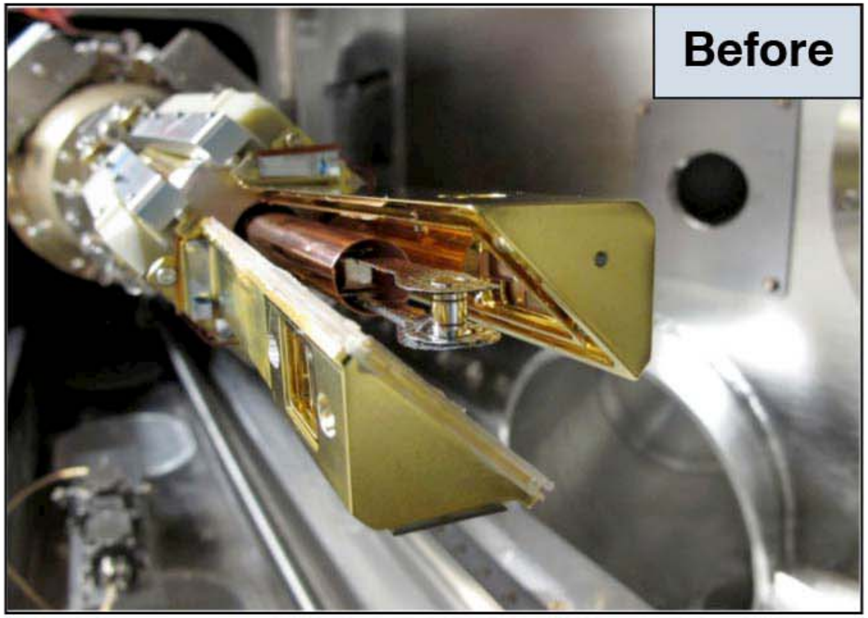
Final x-ray images of the THD ice layer at 17:54 pm with temperature of 18.6K

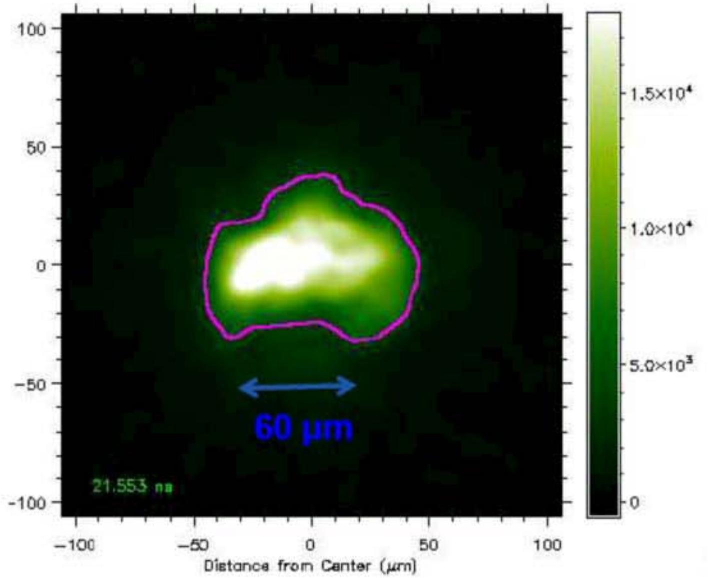
LEH view



Goal is 1000x increase in yield from last year

On Sept. 29th at 8:27 p.m. (PDT), NIC conducted the first cryo-layered target experiment on NIF





- All 192-laser beams fired 1 MJ of laser energy into the hohlraum
  - Radiation drive was consistent with earlier shots at this energy (~290 eV)
  - Preliminary yield estimate was ~1 x 1013 neutrons based on nToF
- The capsule was filled with a mixture of tritium, hydrogen and deuterium tailored to enable the most comprehensive physics results, not to demonstrate ignition
- All systems operated successfully and 26 target diagnostics acquired data

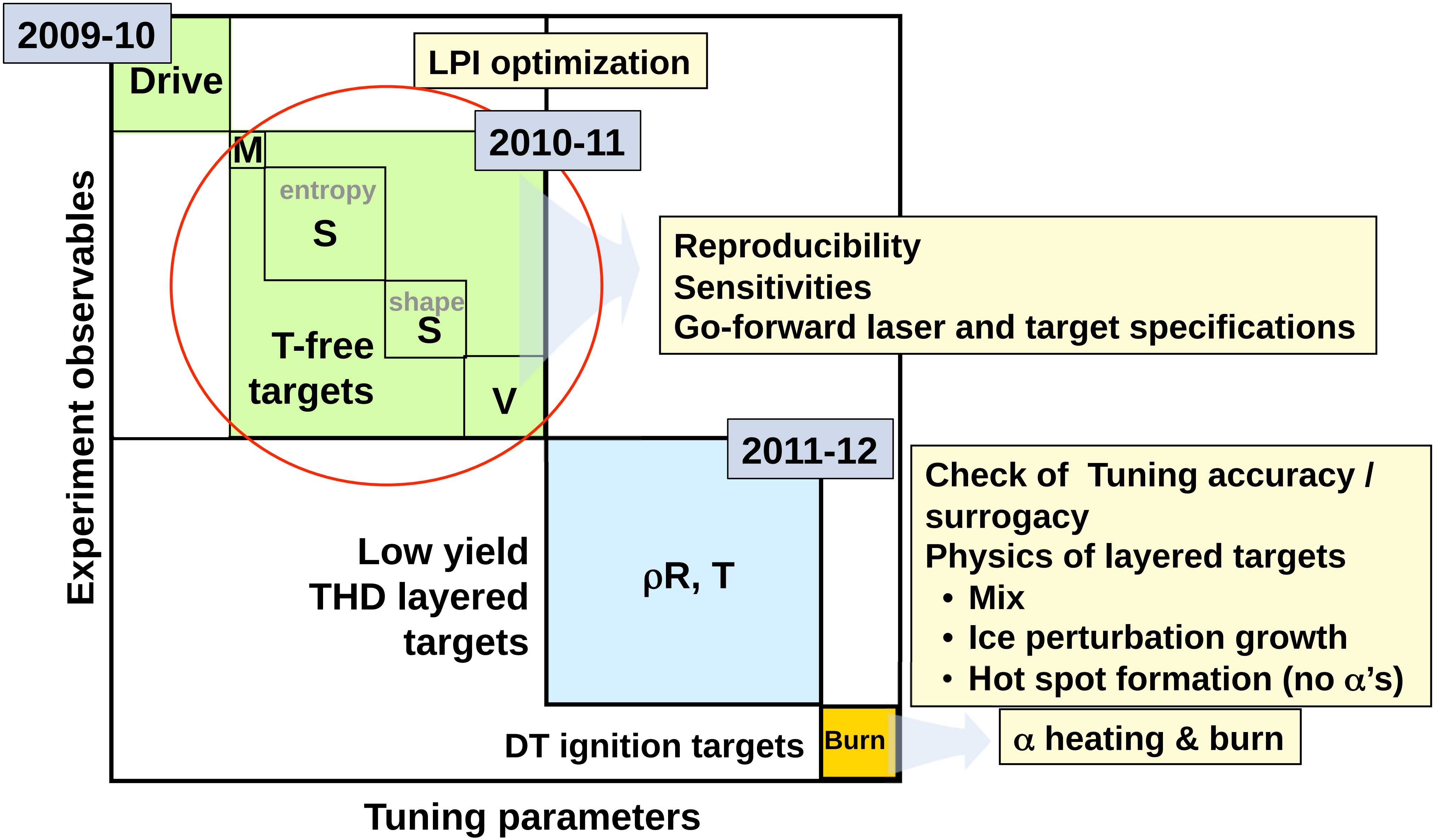
Preliminary results of the target performance are very encouraging, analysis is continuing

This experiment demonstrated ability of the NIC team to conduct layered implosion experiments

- We have successfully fielded a indirect drive layered implosion experiment with thermonuclear fuel [6% D, 22% H, 72% T]
  - Capsules are driven in hohlraums with 288 eV radiation temperature heated by 1 MJ laser energy from 192 smoothed beams on NIF
  - The capsule was shot with a smooth 65 μm thick nuclear fuel layer at 1.5 degrees below the triple point
  - Successfully fielded 11 nuclear and 8 x-ray diagnostics
    - 14.1 MeV DT yield
    - down scattered neutrons (10-12 MeV)
    - Ion temperature T_{ion}
    - Capsule Shape and x-ray emission
- Experiments show compression, yield and fuel rho-r consistent with implosions that are not tuned
  - Compressed to 40 microns (x1.5 more than a symcap)
  - Yield of 8e12 and 2.8% down scattered neutron fraction

The fielding of the first layered capsule implosions has marked the beginning of the ignition campaign on NIF

Tuning of mix, entropy, shape and velocity is prerequisite for improving THD/DT implosion performance

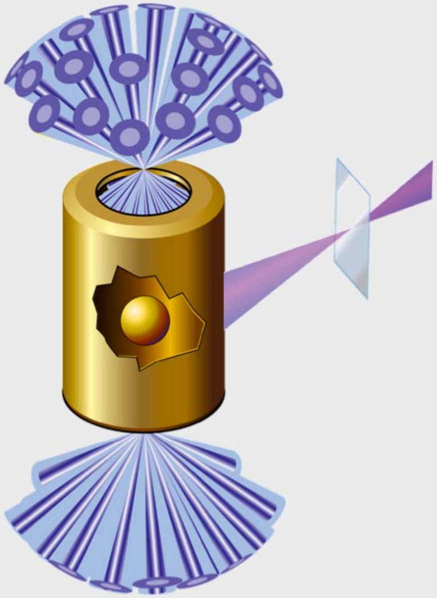


Adiabat | Shape

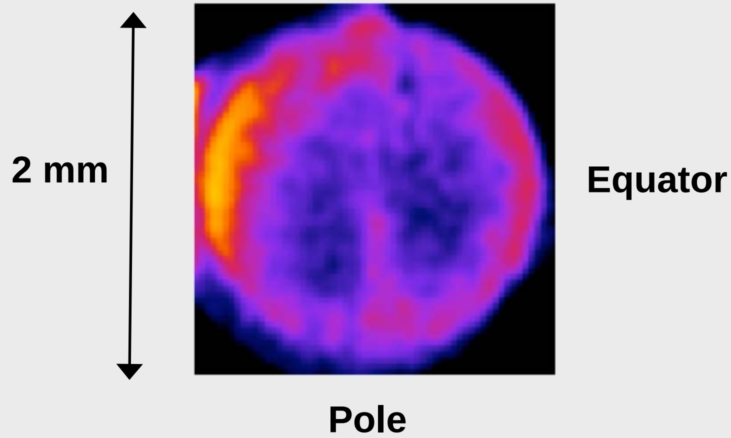
We have demonstrated the ability to measure symmetry of 1st shock required to interpret single-point shock timing

Drive asymmetry is inferred from reemission sphere limb brightness vs angle

Bi sphere "Reemit" replaces layered capsule



hν = 700 eV X-ray image

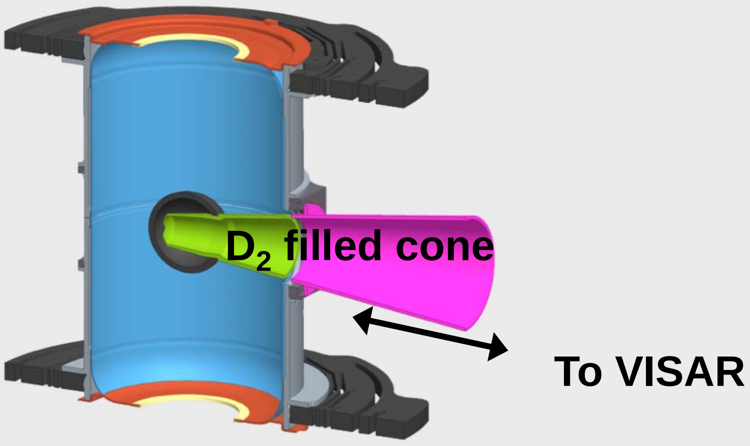


- **Accuracy of ±5% in pole-to-equator drive asymmetry meets requirement**
- **First shot shows equator is driven with 15% higher flux as expected**

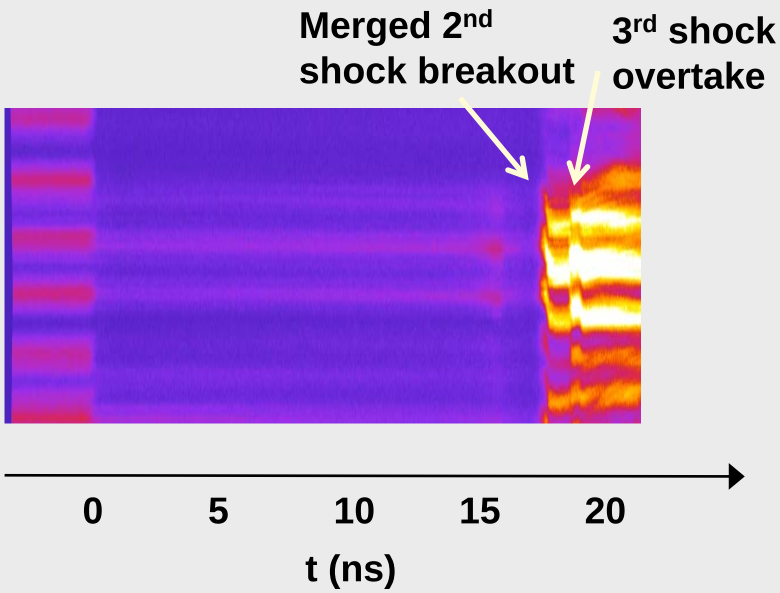
And to measure shock velocity history as it compresses fuel which is critical for minimizing adiabat

Shock velocities and overtake times and distances are measured from fringe shifts off reflected reentrant optical velocity interferometer (VISAR)

Liquid D_2-filled Cone-in-sphere "Keyhole" replaces layered capsule



Streak record of VISAR

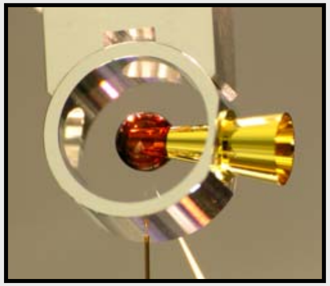


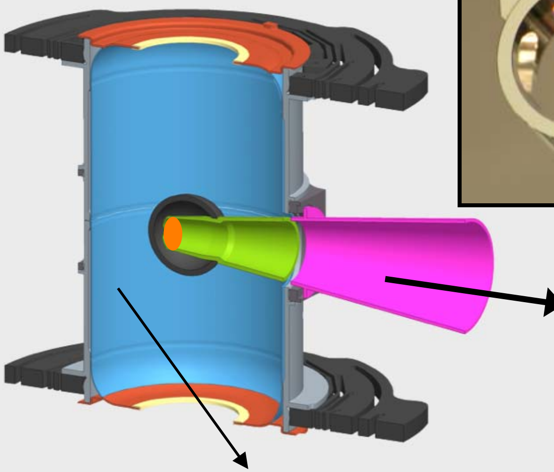
- **Accuracies of 2% in velocity and 50 ps in timing meet requirements**
- **First shots have shown weaker than expected 1st shock, overtaken earlier than expected by 2nd then 3rd shock**

We have also demonstrated the ability to measure final 4th shock timing, critical to setting final fuel adiabat

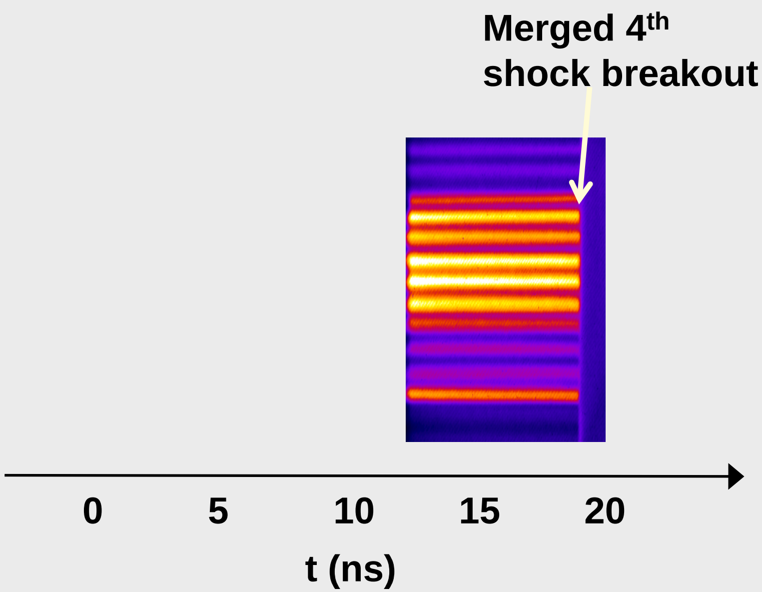
We measure 4th shock strength from break-out time in Au witness plate

Liquid D_2-filled capsule with Au witness plate at end of cone replaces layered capsule





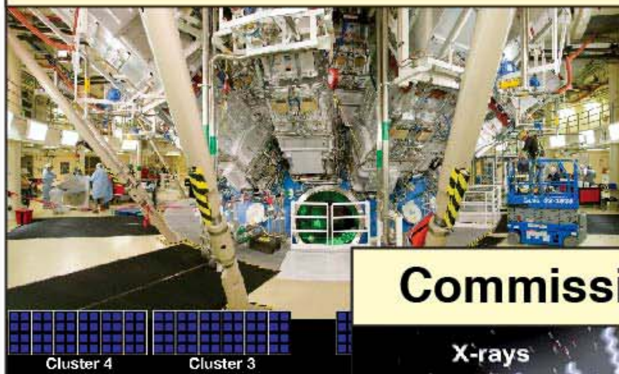
Streak record of VISAR



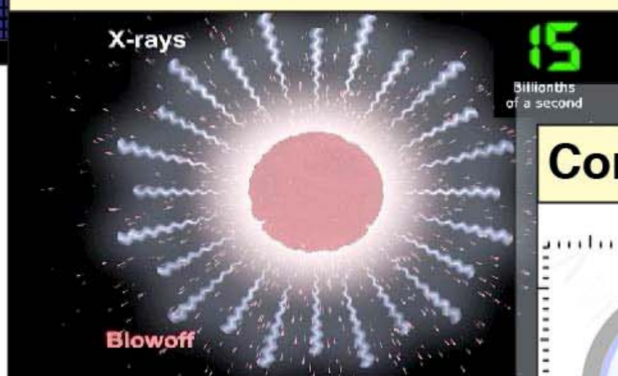
- Accuracy of 50 ps in shock break-out timing meet requirements
- First shot has shown slightly delayed 4th shock (< 300 ps)

Ignition: Next Steps

Commission laser

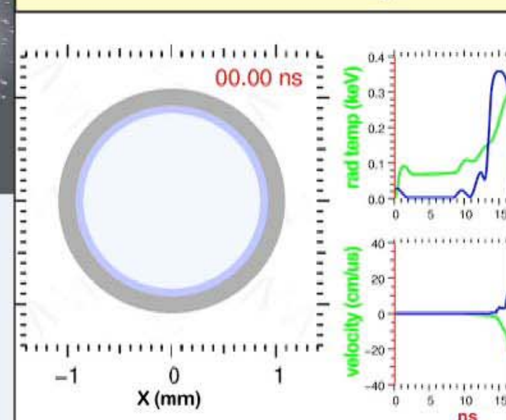


Commission hohlraum



- Hohlraum temperature scales to ignition point design
- Laser scatter losses <15%
- Symmetry control demonstrated

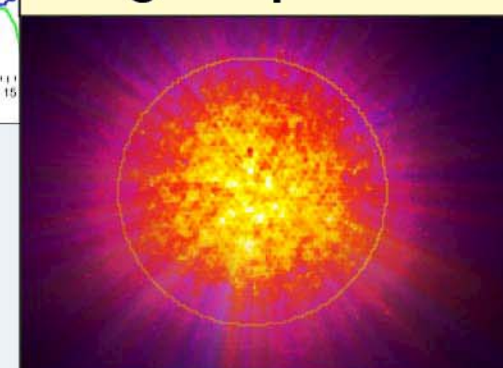
Commission capsule



Underway

- Measure ablator velocity and start mix

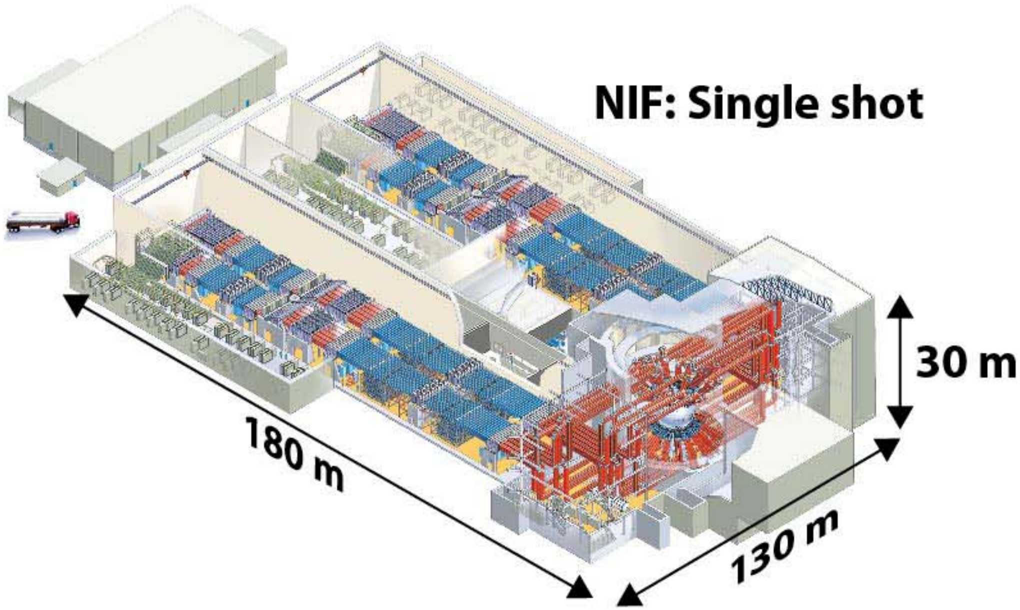
Commission layered target implosions



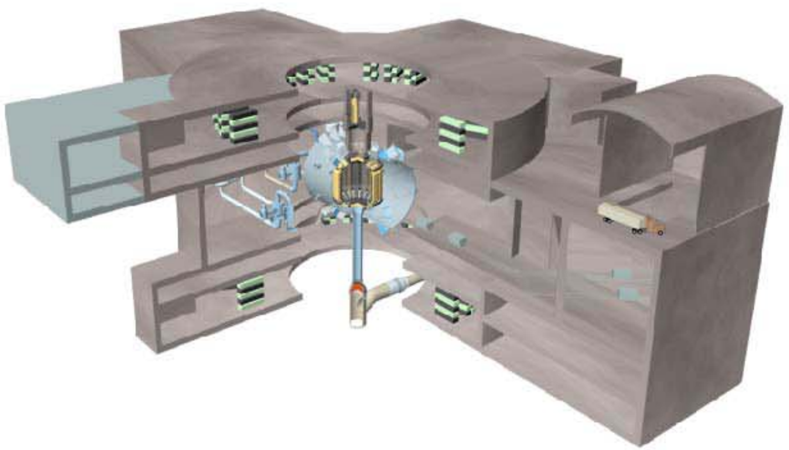
Ignition on NIF will enable development of Laser Inertial Fusion Energy (LIFE)

Experience with NIF, and evidence from the ignition campaign, are being used to define a path for LIFE

NIF: Single shot

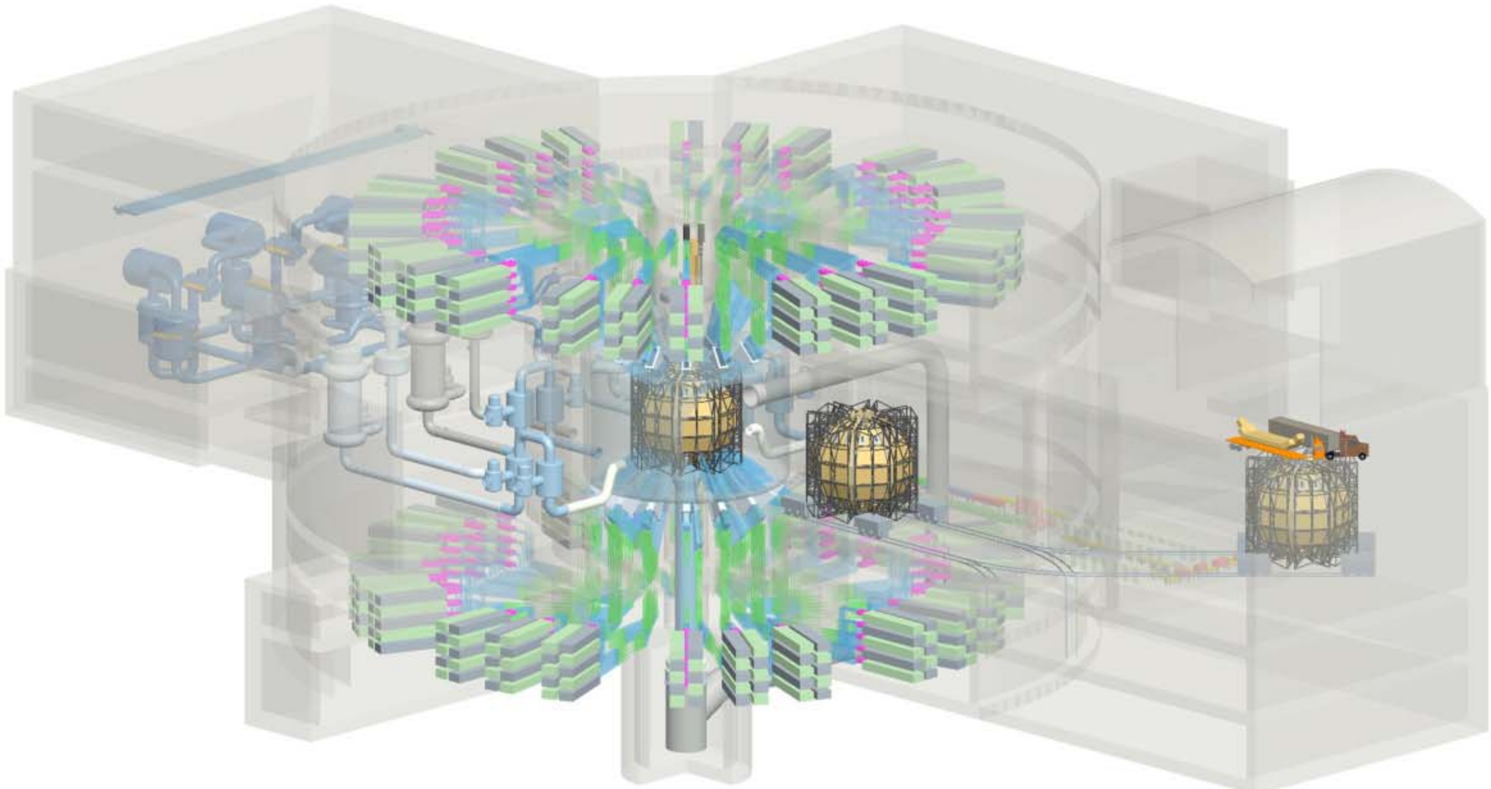


LIFE: 15 Hz



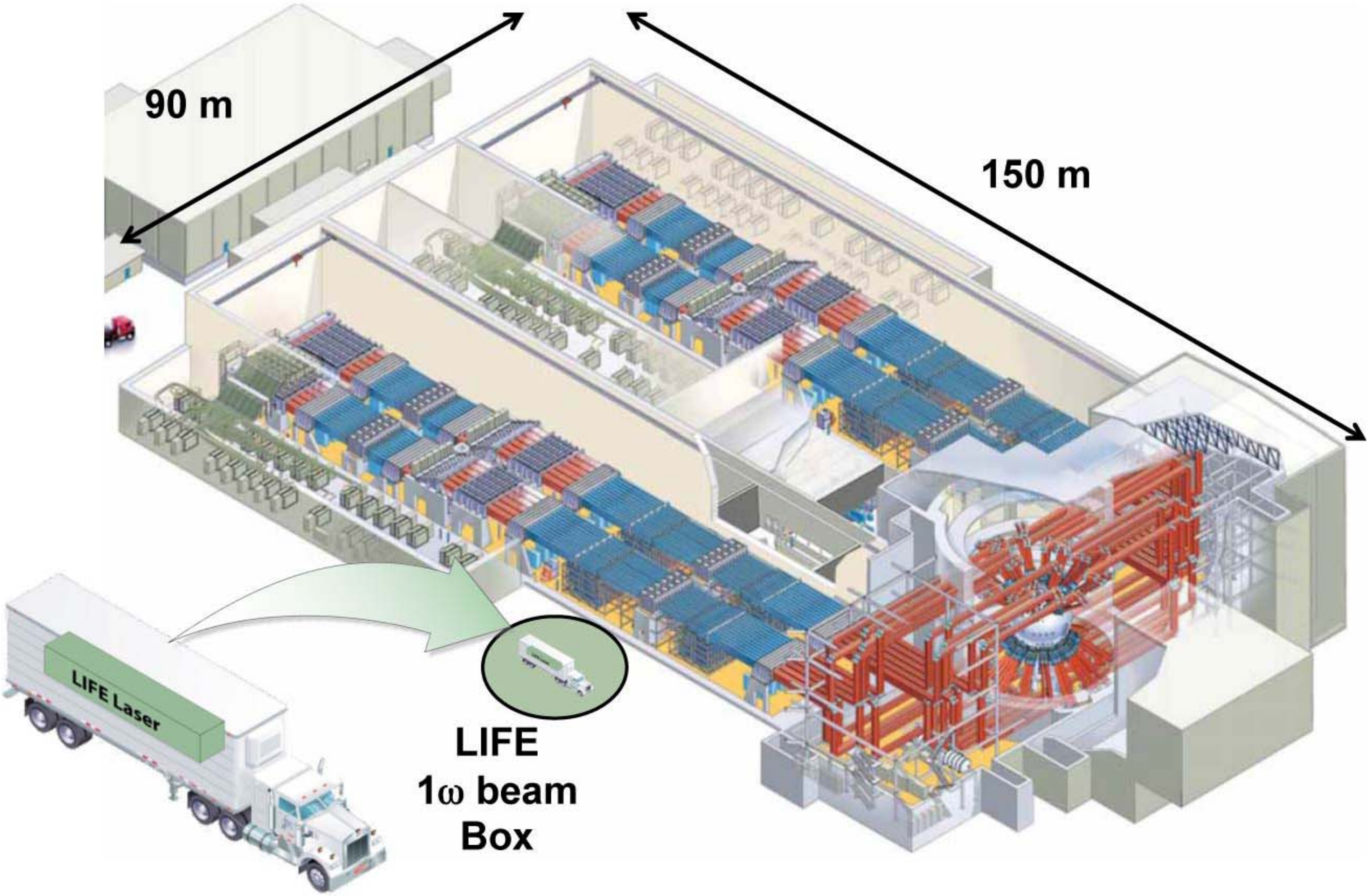
Similar:
- Physical size
- Laser energy
- Target performance
- Concept of operations (LRUs, ...)

An integrated, self-consistent plant design for LIFE has been developed



- NIF-like fusion performance
- Line Replaceable Units for all the high threat systems
- Market based diode laser technology
- Advanced thermo-electric cycle

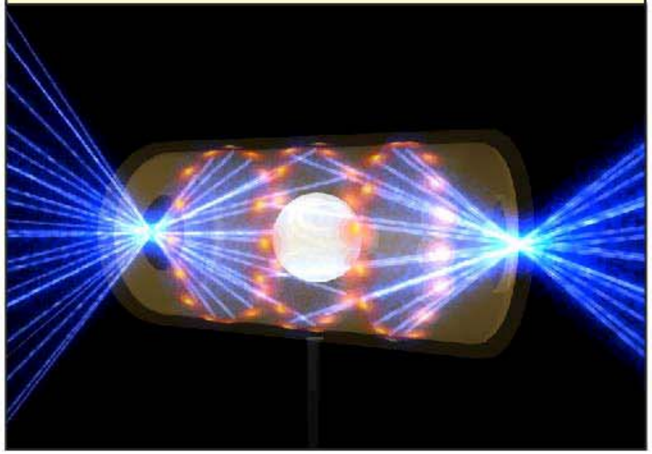
New laser technology allows dramatic improvements in size and efficiency



Delivery Plan

NIF completion 2009

NIF ignition 2011/2012



LIFE demonstration 2020's

LIFE commercial 2030's

Fusion energy - soon enough to make a difference!

00ABC/abc · NIF-1110-20462s2


NIF