NIF and the National Ignition Campaign

Presentation to

Symposium on Recent Advances in Plasma Physics

John Lindl
NIF Programs Chief Scientist

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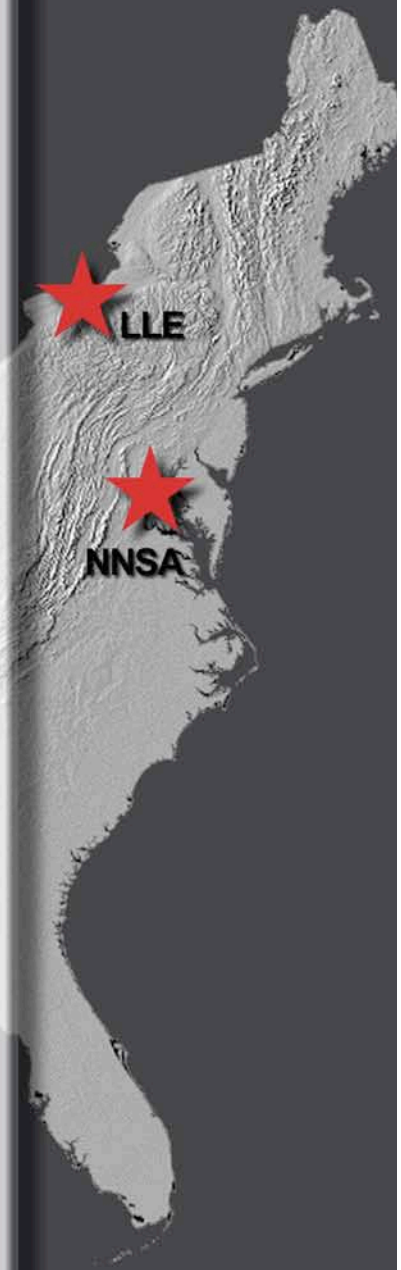

National Nuclear Security Administration

GENERAL ATOMICS

UR LLE

University of California
Lawrence Livermore National Laboratory

Los Alamos NATIONAL LABORATORY

Sandia National Laboratories

All of the pieces for ignition are almost in place

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- The NIF laser and the equipment needed for ignition experiments, including high quality targets, will be available in 21 months
- We have an ignition point design target near 1 MJ with a credible chance for ignition during early NIF operations
- The Laser Plasma Interaction (LPI) uncertainty for the first ignition experiments is bounded by ignition designs from about 1-1.3 MJ in laser energy or by a range of hohlraum temperatures from 270-300 eV
- We have an Early Opportunity Shots (EOS) campaign with 96 beams planned to start in 13 months which will allow us to choose the optimum hohlraum temperature and laser energy for initial ignition experiments.
- The initial ignition experiments only scratch the surface of NIF's potential which includes high yields with green light and greatly expanded opportunities for the uses of ignition by decoupling compression and ignition in Fast Ignition (FI).

National
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Facility

NIF is a 192 beam laser organized into "clusters", "bundles" and "quads"

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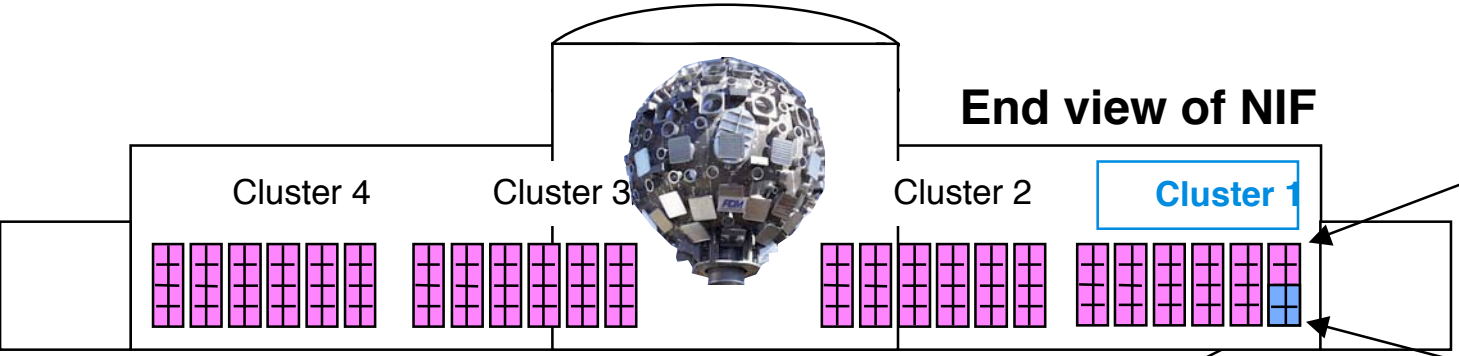
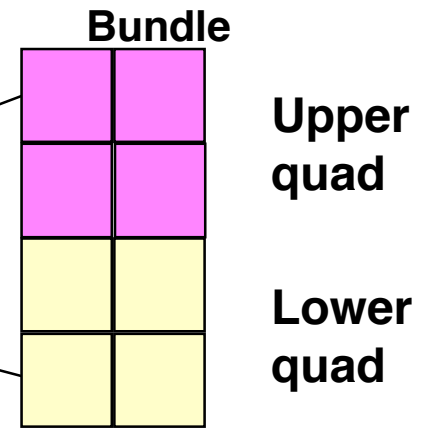
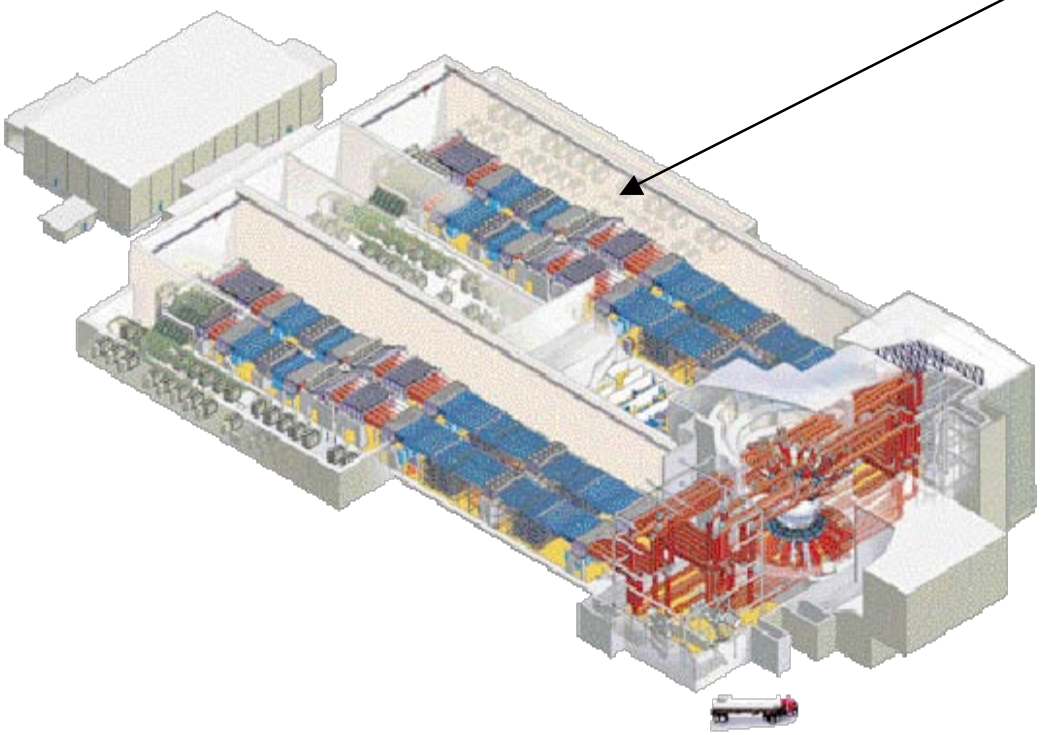
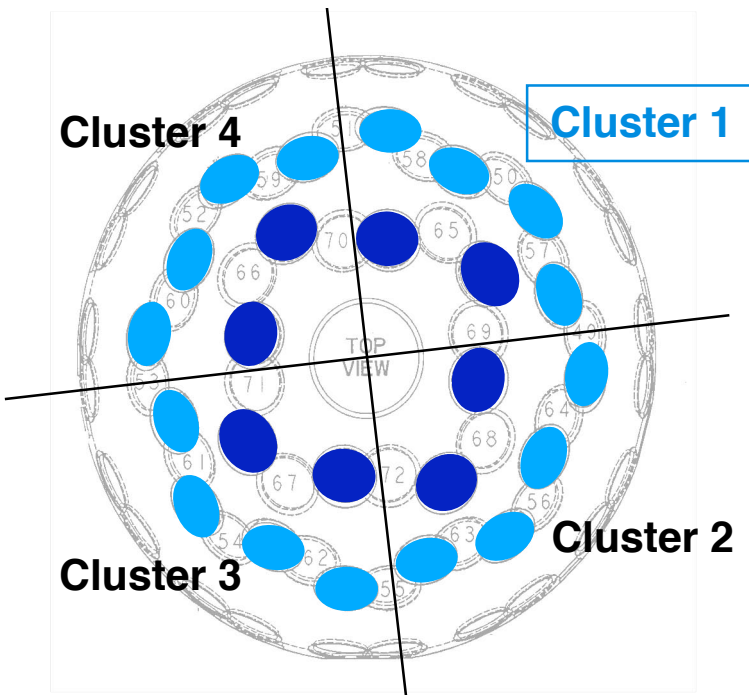
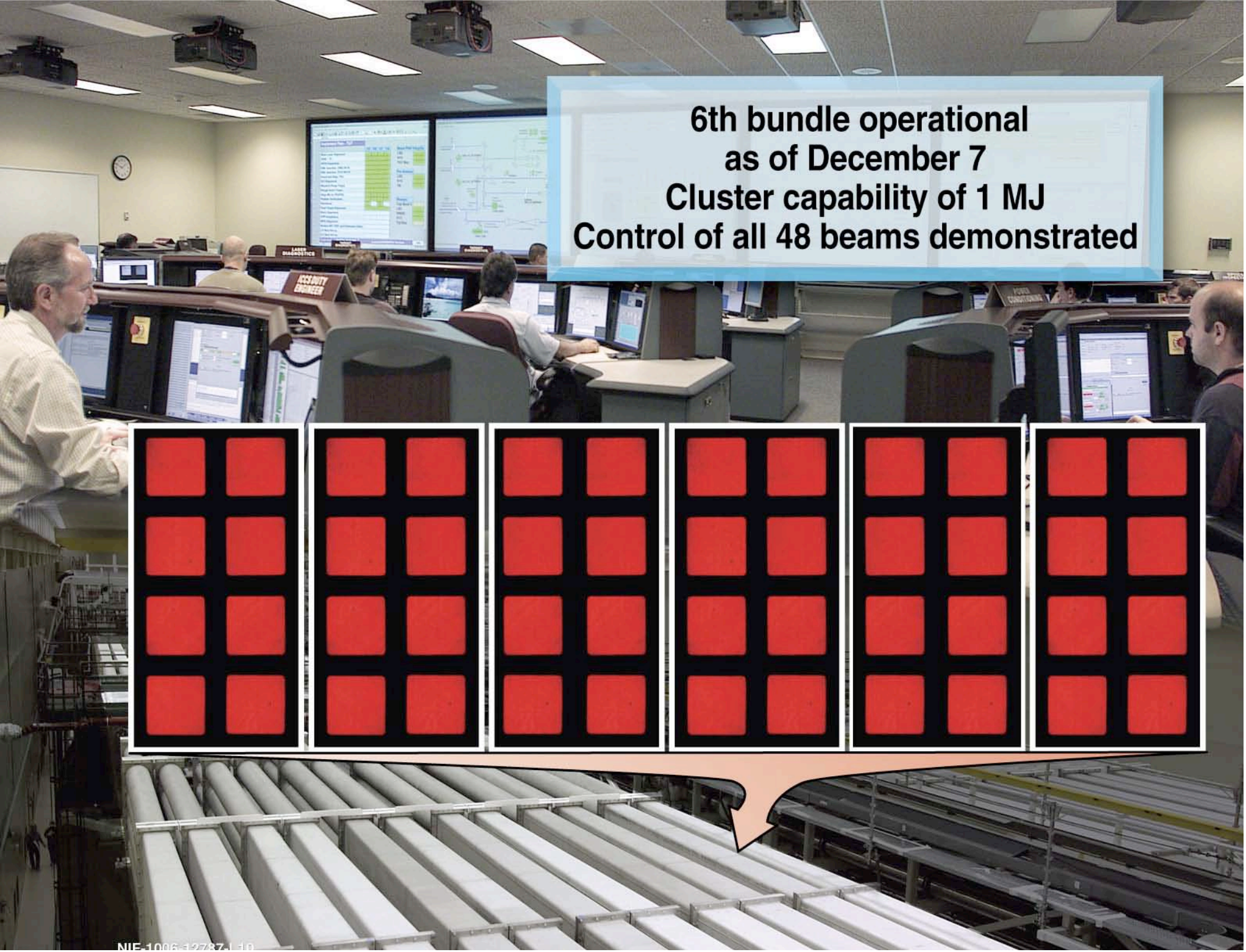






Top view of target chamber (upper quads)




6th bundle operational
as of December 7
Cluster capability of 1 MJ
Control of all 48 beams demonstrated
NIF-1006-12787-L10

1.8 MJ NIC ignition point design, energy, power, pulse shape & beam smoothing were achieved simultaneously (single beam)

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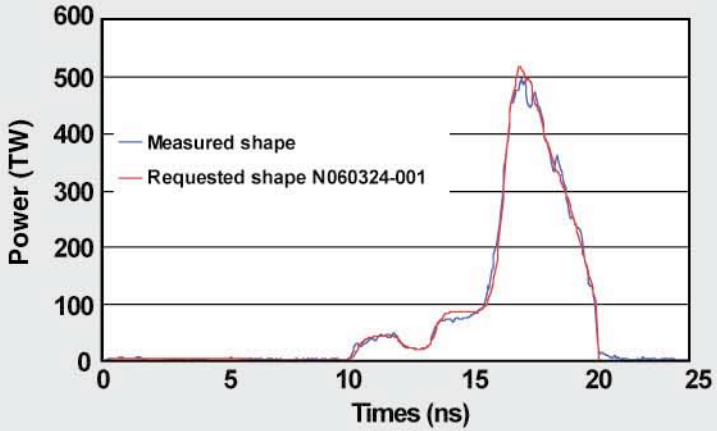
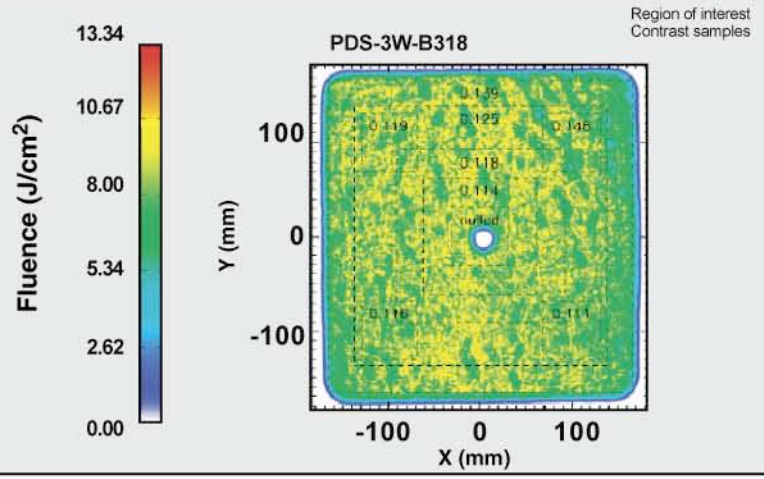
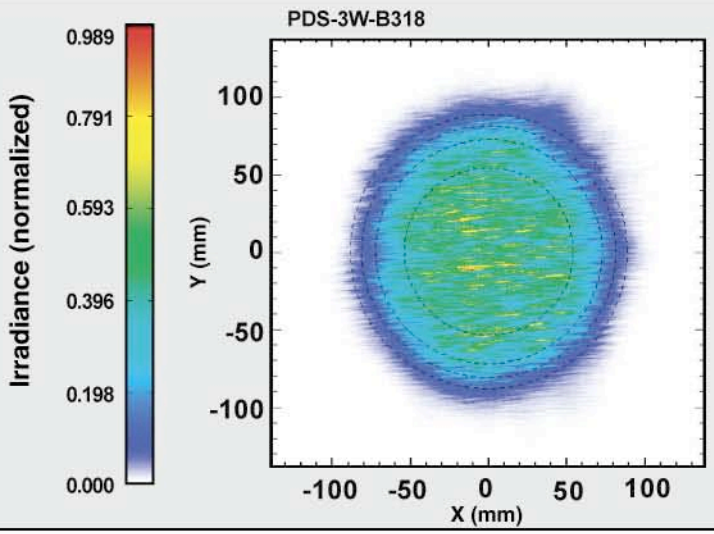
3ω Pulse Shape (500 TW)



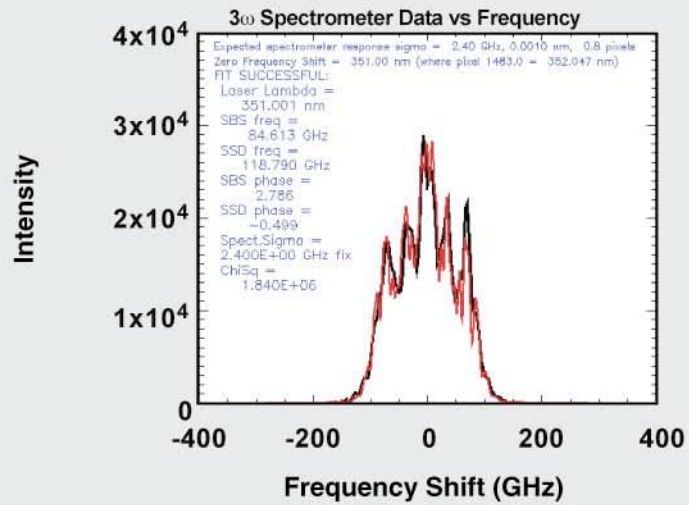
3ω Field Profile (CR = 12.5%)



3ω Focal Spot (1.3 × 1.2 mm²)



3ω SSD Bandwidth (100GHz)



NIF-0506-11982

The NIF point design has a graded-doped, beryllium capsule in a $U_{0.75}Au_{.25}$ hohlraum driven at 300 eV

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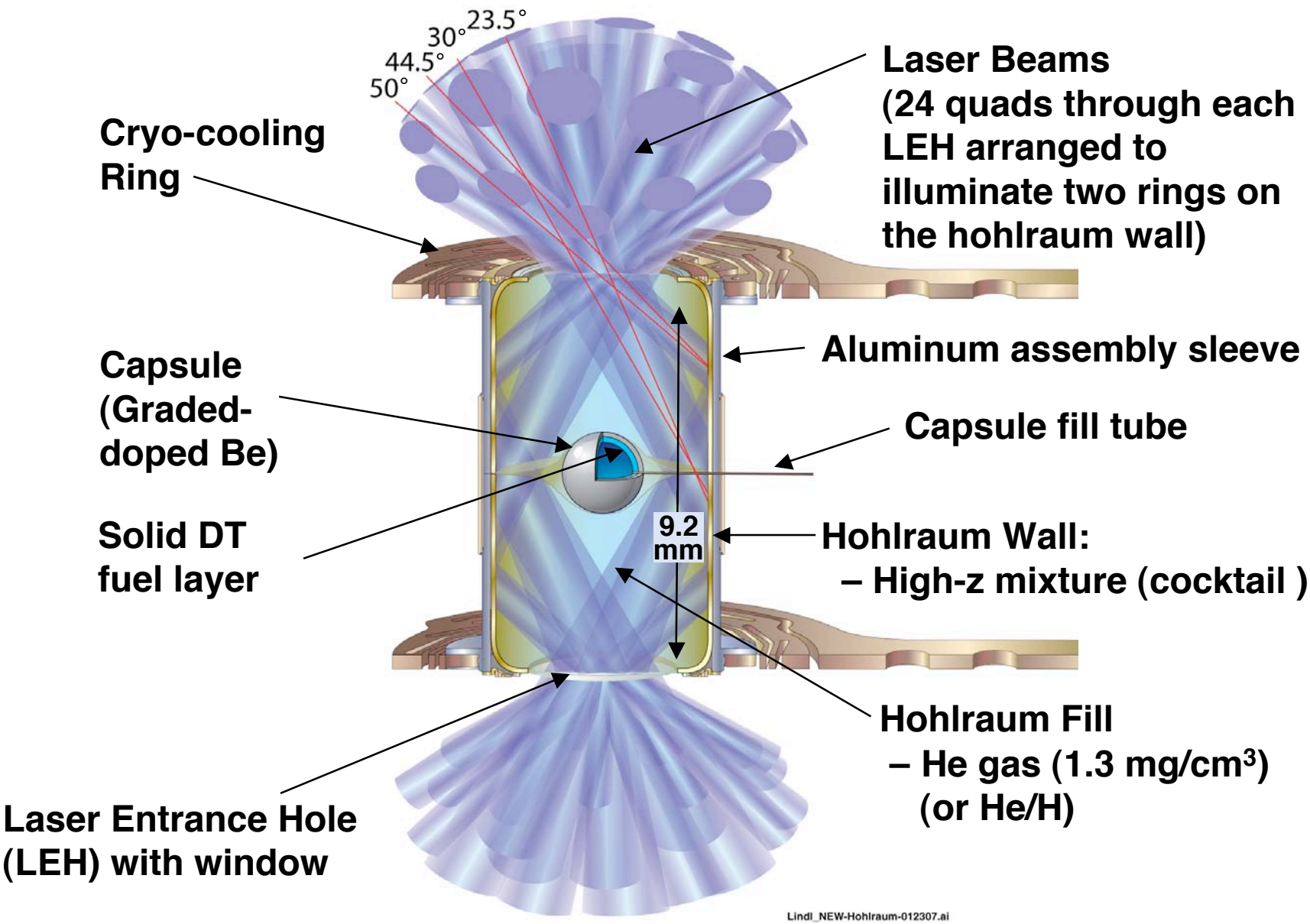

Optimized 2D symmetry calculations meet the point design requirements

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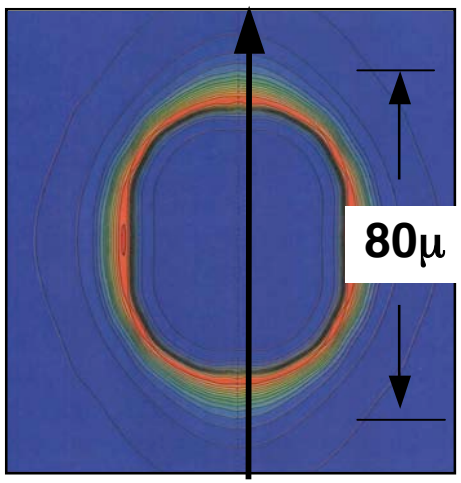
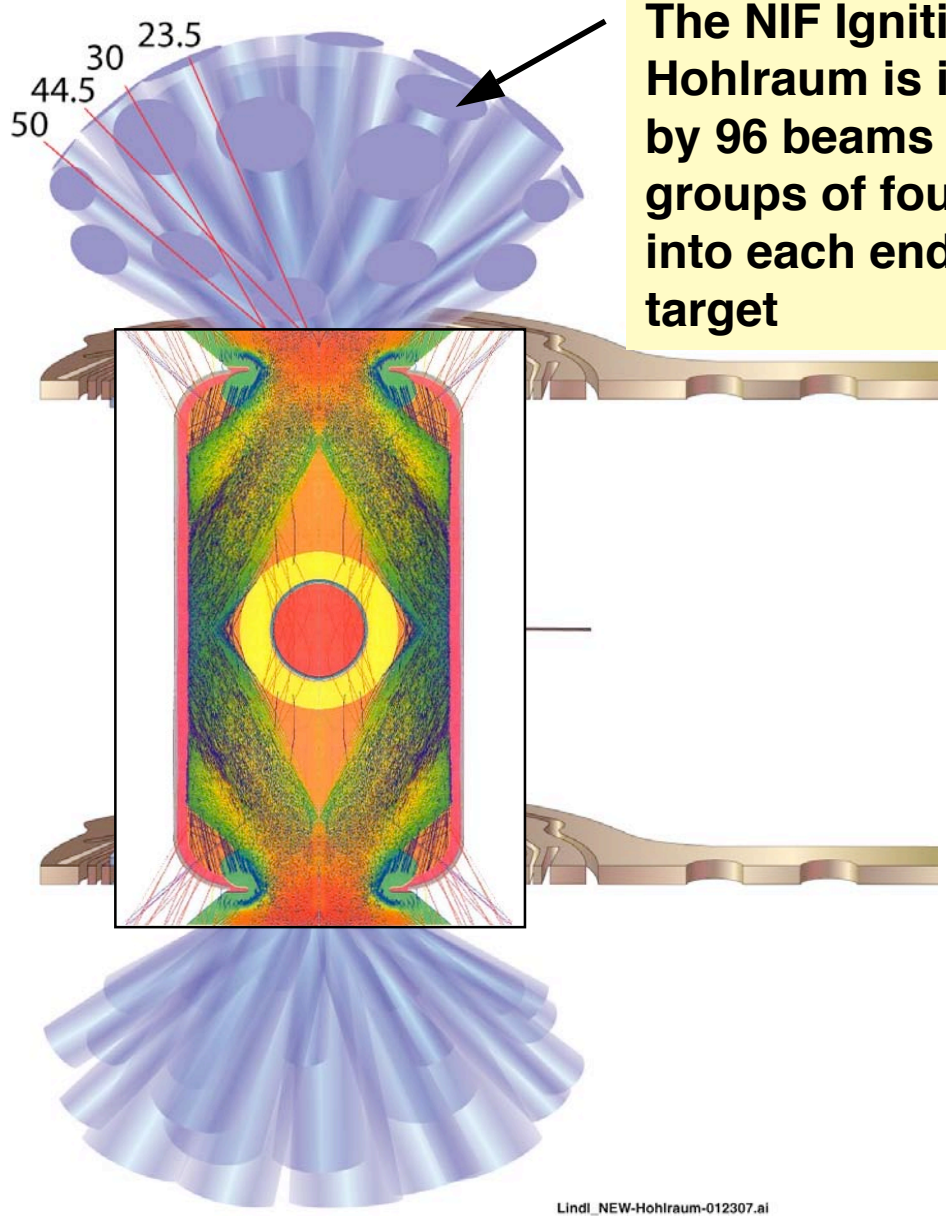
Be capsule fuel region at ignition





The NIF Ignition Hohlraum is illuminated by 96 beams in 24 groups of four beams into each end of the target

- **The imploded fuel core shows very little residual angular variation from the NIF multi-cone geometry**

ASC computers are essential for a wide variety of 3D effects which impact NIF ignition targets

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- Integrated hohlraum and capsule calculations - low spatial frequency perturbations (l=8 or less)
  - Hohlraum radiation flux asymmetry
  - Pointing errors
  - Power Imbalance
  - Capsule misplacement in the hohlraum
  - Hohlraum misalignment in the chamber
  - Missing beams or other off normal operation
  - Holes in the hohlraum or other inherently 3D structure
- Capsule only calculations - intermediate to high spatial frequency perturbations (l=30 to 1000)
  - DT ice roughness
  - Ablator roughness
  - Ablator microstructure
- Single Beam - Very high spatial frequency perturbations
  - laser wavelength and laser frequency scale features in the incident beam and in laser plasma interaction in the hohlrau

The HYDRA code is used on ASC computers for 3D hohlraum symmetry and other low spatial frequency effects

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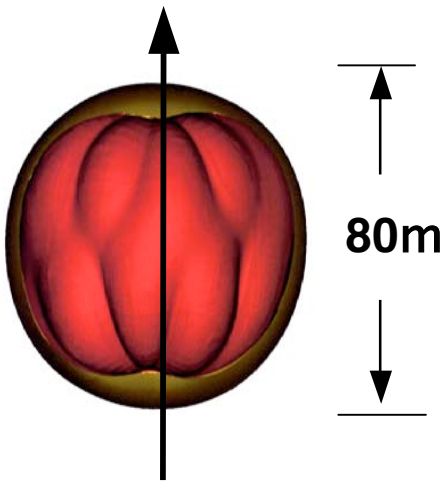
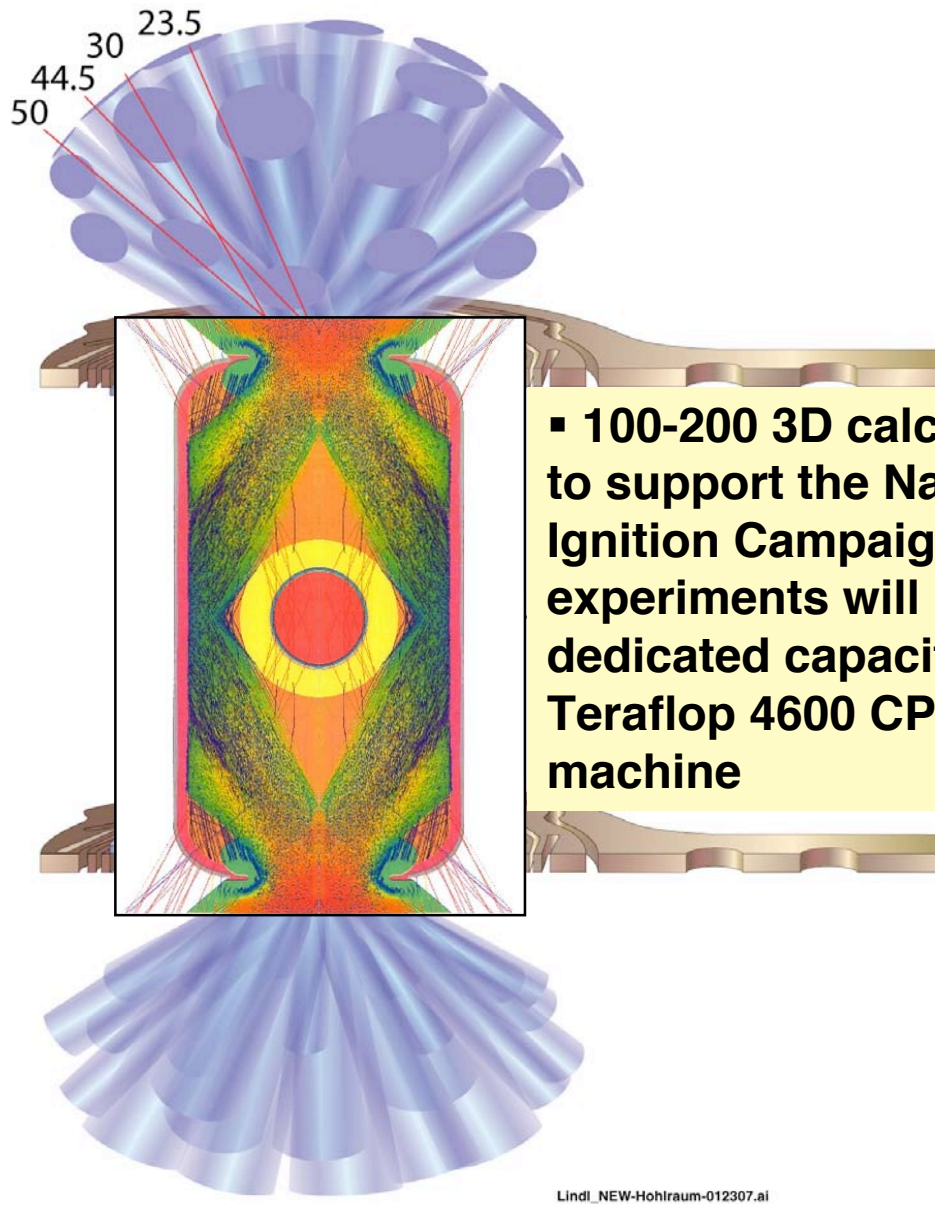
Be capsule fuel region at ignition

600 g/cc surface





- 100-200 3D calculations/yr to support the National Ignition Campaign experiments will require the dedicated capacity of a 50 Teraflop 4600 CPU class machine

- A 3D hohlraum calculation capable of resolving l=8 radiation asymmetry requires about 0.2M CPU hours

Resolving laser wavelength scale phenomena in the propagation of a laser beam in an ignition scale plasma is a grand challenge problem.

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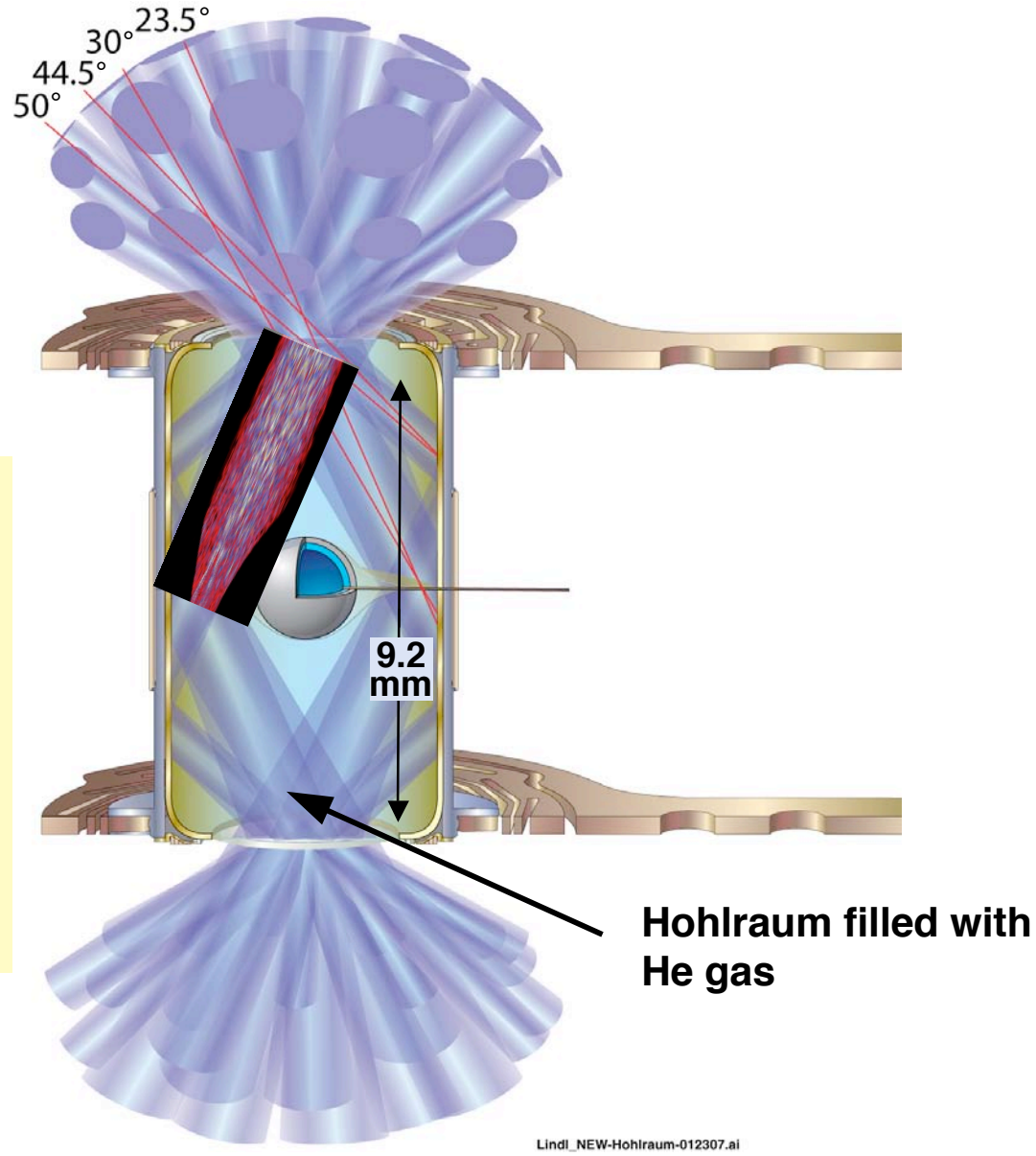
▪letterbox" simulations capture the essential physics for "near 2D" situations, like a NIF hohlraum, "

▪ A letterbox run for 10's of picoseconds using the code pF3D requires 8 Terabytes of memory and ~ 2.5M cpu-hours on the 8000 processor Atlas Machine or ~ 15M cpu-hours on 32,000 processors of BG/L



A 10 petaflop ASC capability will enable integrated hohlraum and capsule simulations which include wavelength scale laser-plasma interaction and beam propagation

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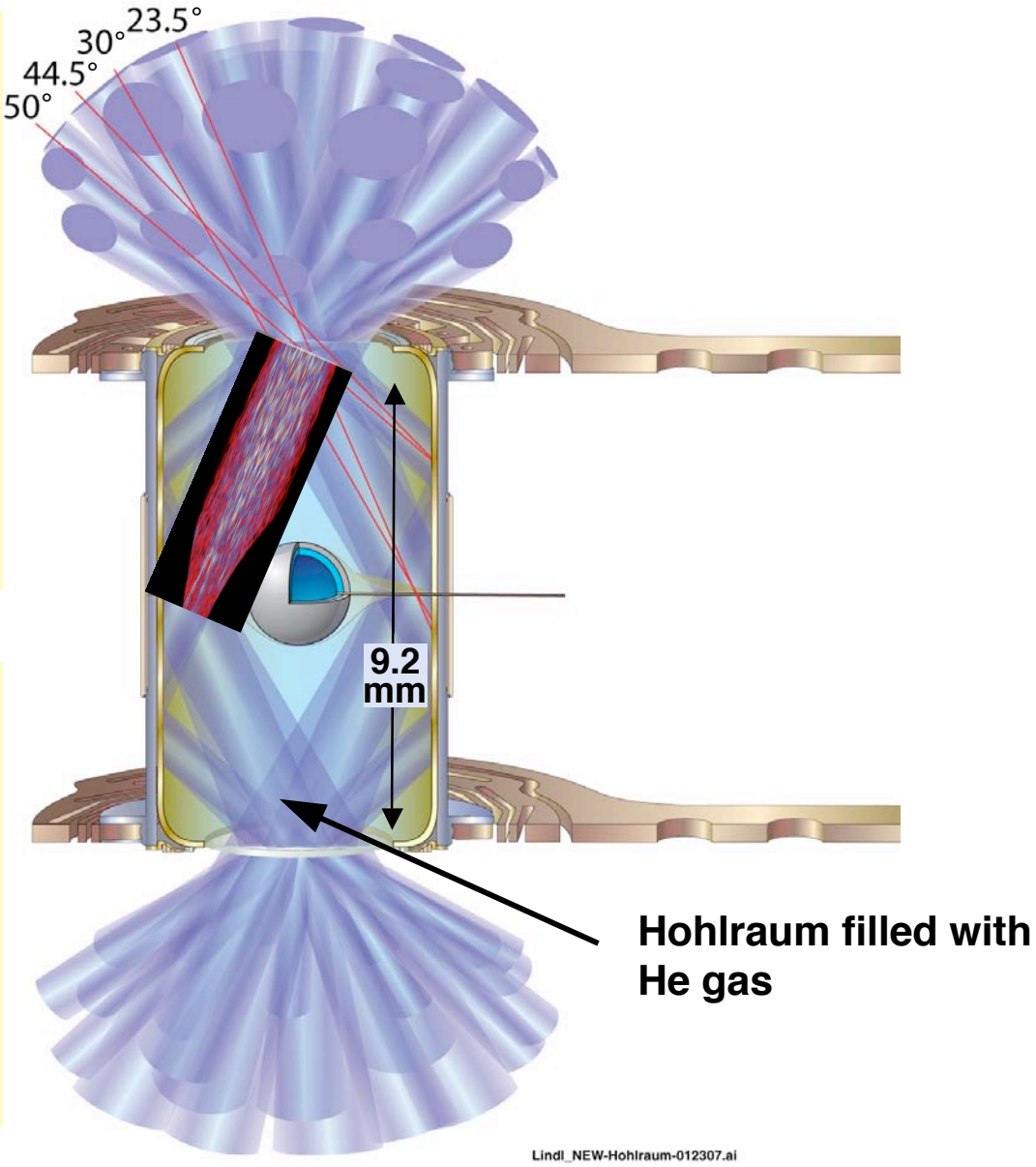
- With a 10 petaflop class machine, in “near 2D conditions”, we could begin to run pF3D as a module in HYDRA, simulating each of the 4 types of NIF quads in a “letterbox approximation” for ~100 times during a full implosion

- This capability could open up the operating conditions for ignition experiments on NIF and significantly simplify the experimental campaigns. Full utility would require ~0.1 - 1 exaflops



The ignition point design capsule is subject to hydrodynamic instability over a wide range of spatial scales

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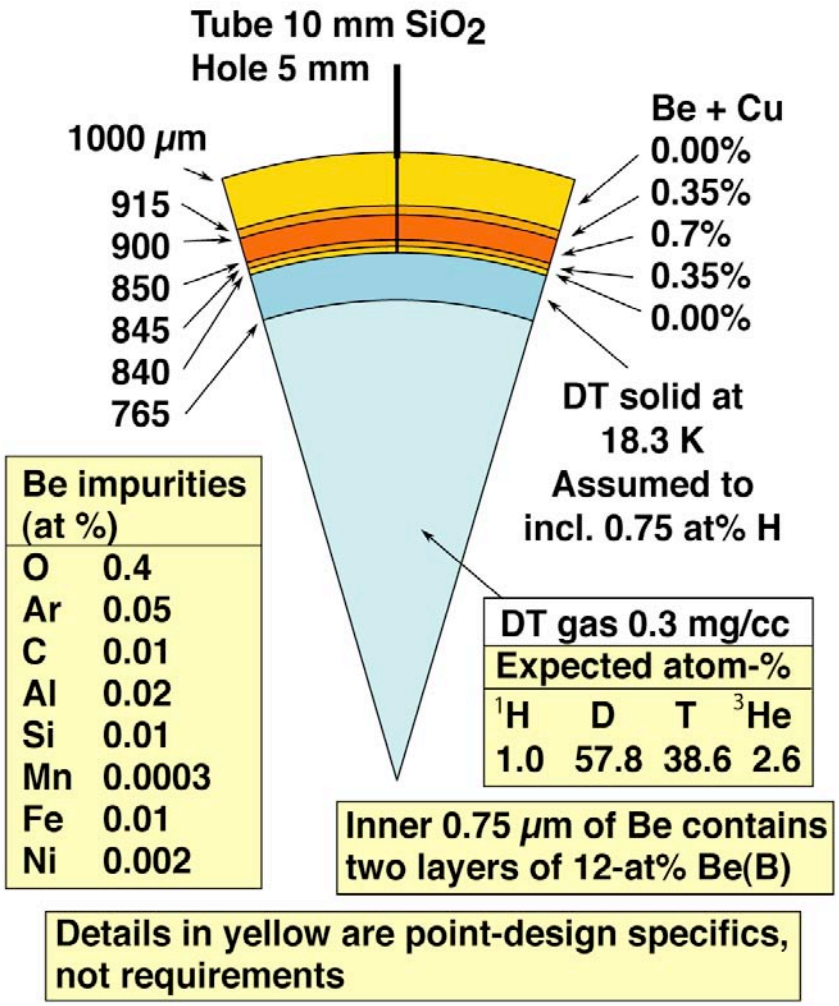
- Outer surface of the Be ablator - up to about mode 120 during the acceleration process
- Inner surface of the DT fuel - up to about mode 30 during deceleration to ignition conditions
- Interface between Be and DT - up to about mode 1000 during acceleration

There is coupling between the interfaces and coupling between modes when the instability becomes highly non-linear

300 eV ignition point design capsule



Details in yellow are point-design specifics, not requirements

Detailed effects of capsule surface roughness are evaluated using HYDRA in separate stand-alone calculations

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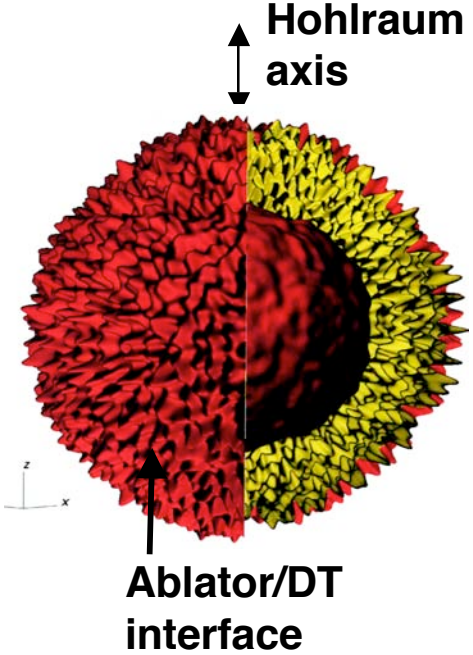
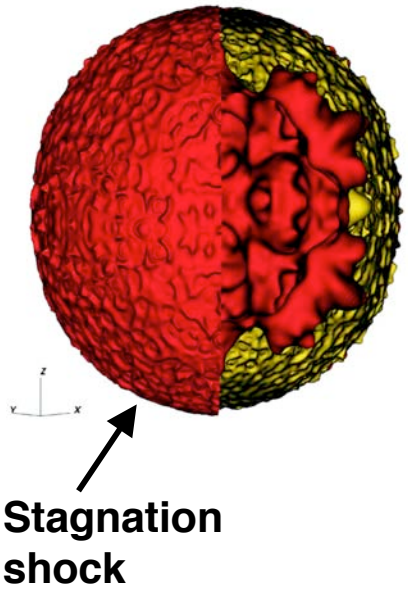
140 ps Before Ignition Time	Ignition Time
	
60 g/cc density isosurface	400 g/cc density isosurface (different scale)

- 3D radiation asymmetry is inferred from integrated hohlraum simulation
- Nominal "at spec" capsule fabrication perturbations are applied on the DT ice and the ablator

- a full sphere covering modes 1-30 or an octant covering modes 4-120 requires about 170 million zones and ~ 4 million cpu hours on 4000 processors of purple

Hydrodynamic instabilities at the capsule ablator-fuel interface are a particularly challenging problem

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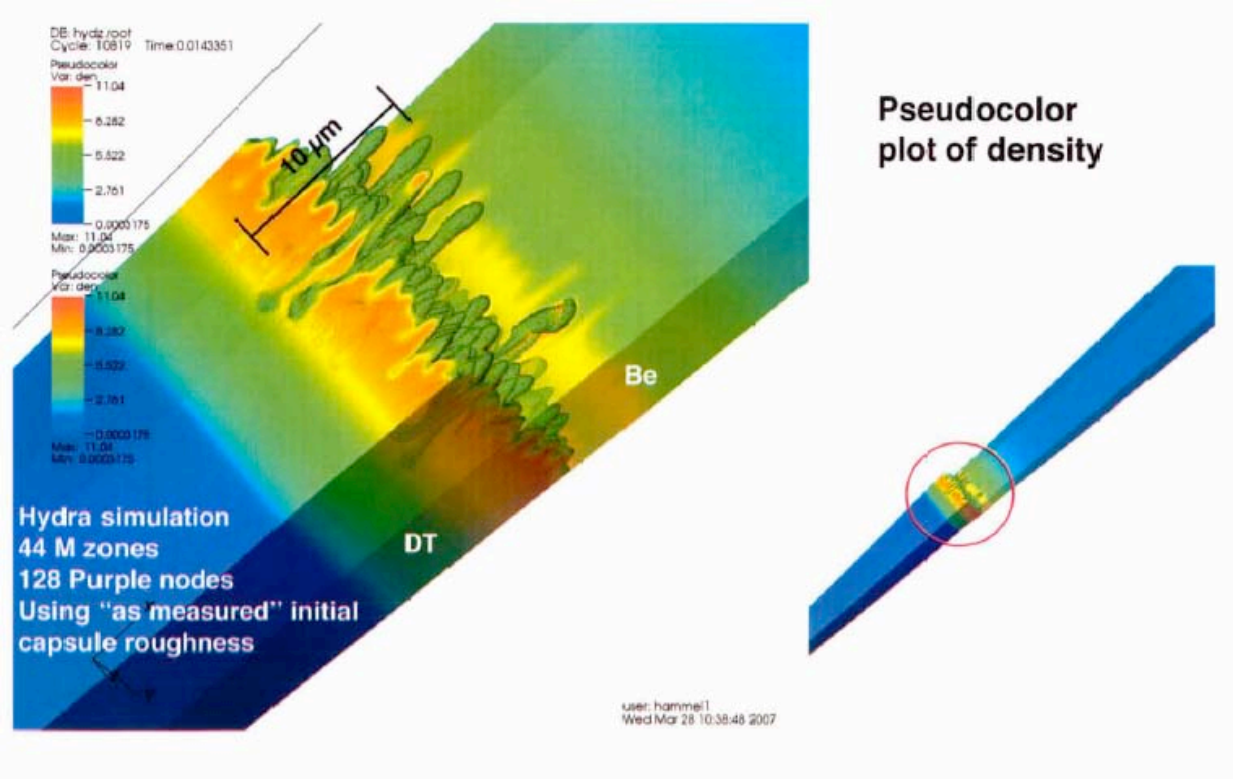
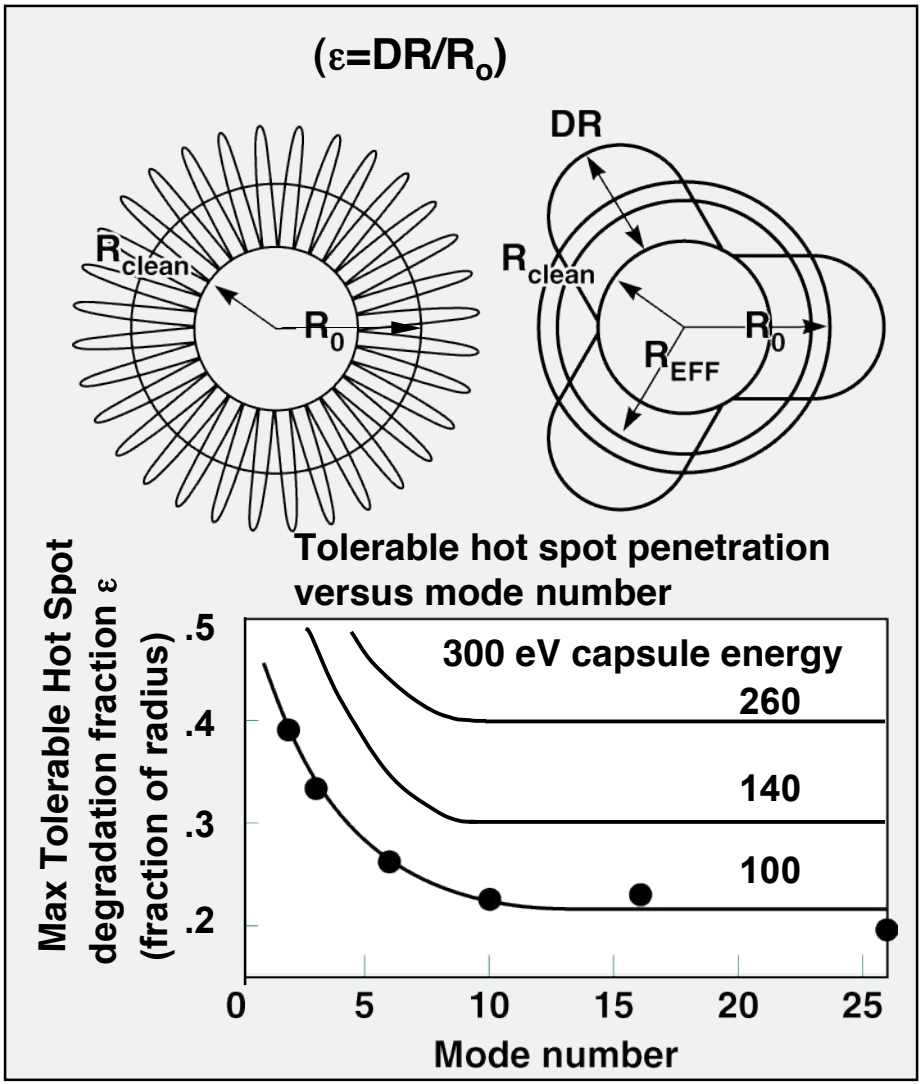
- Calculations resolve instability growth in 3D, up to mode 1000, at the Be/DT interface

- Benchmark calculations for a 4.5-9 degree wedge using the HYDRA Code require 44-176 million zones and 1-4 million CPU hours on 1024-4096 processors of Purple



The impact of most 3D effects that degrade an implosion can be specified as a hot spot degradation fraction



R. Kishony and D. Shvarts Phys. Plasmas **8** (2001) 4925

- **Low spatial frequency Perturbations**
  - Hohlraum asymmetry
  - Pointing errors
  - Power Imbalance
  - Capsule misplacement in chambe
- **High spatial frequency Perturbations**
  - DT ice roughness
  - Ablator roughness
  - Ablator microstructure

- **The hot spot penetration is the fraction of the hot spot radius perturbed by the various sources of error**
- **The specifications developed for NIF ignition designs result in a hot spot penetration of ~20% for short wavelength modes**

Ignition point design optimization must balance LPI effects, laser performance impacts, and capsule robustness

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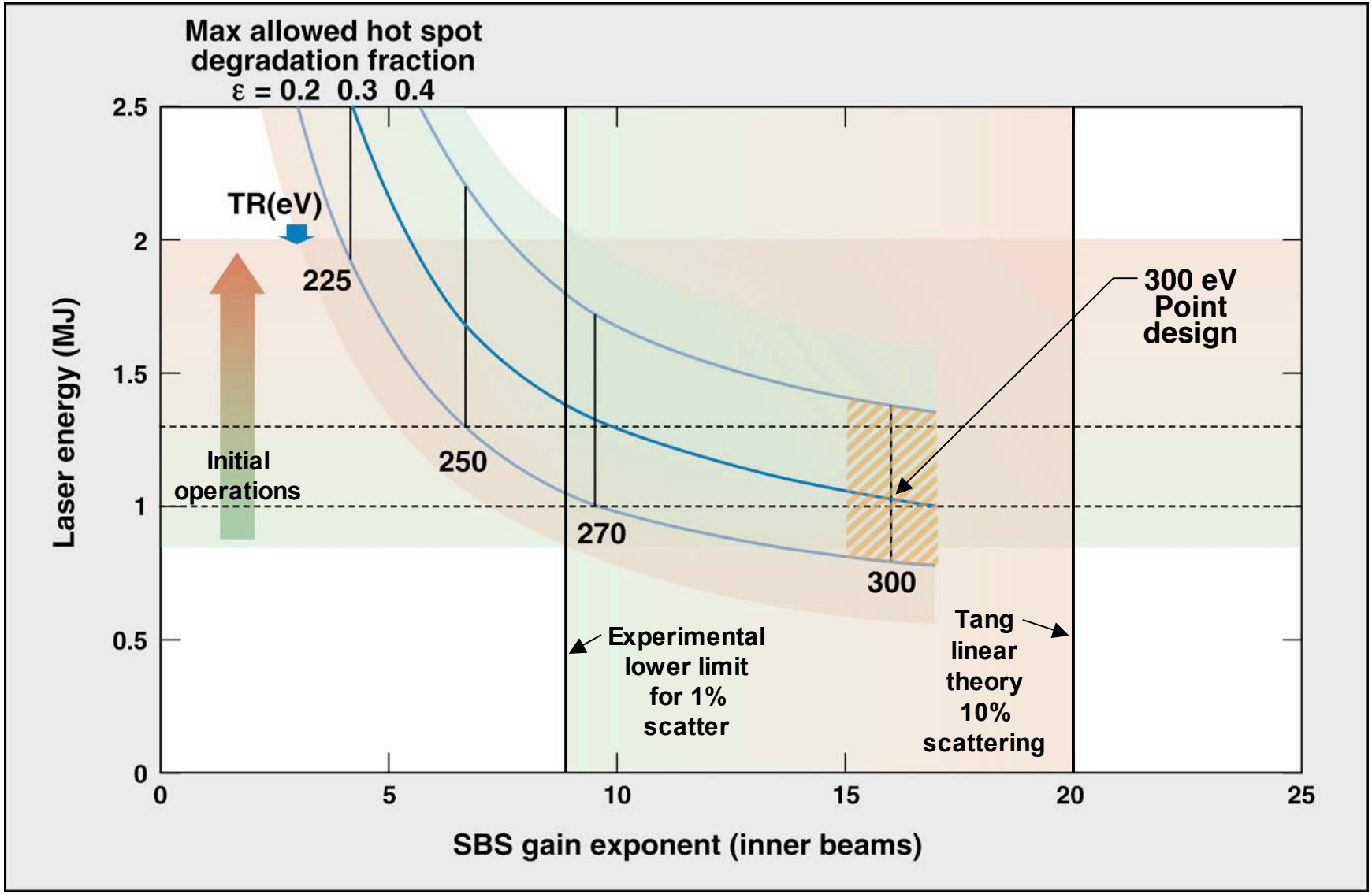

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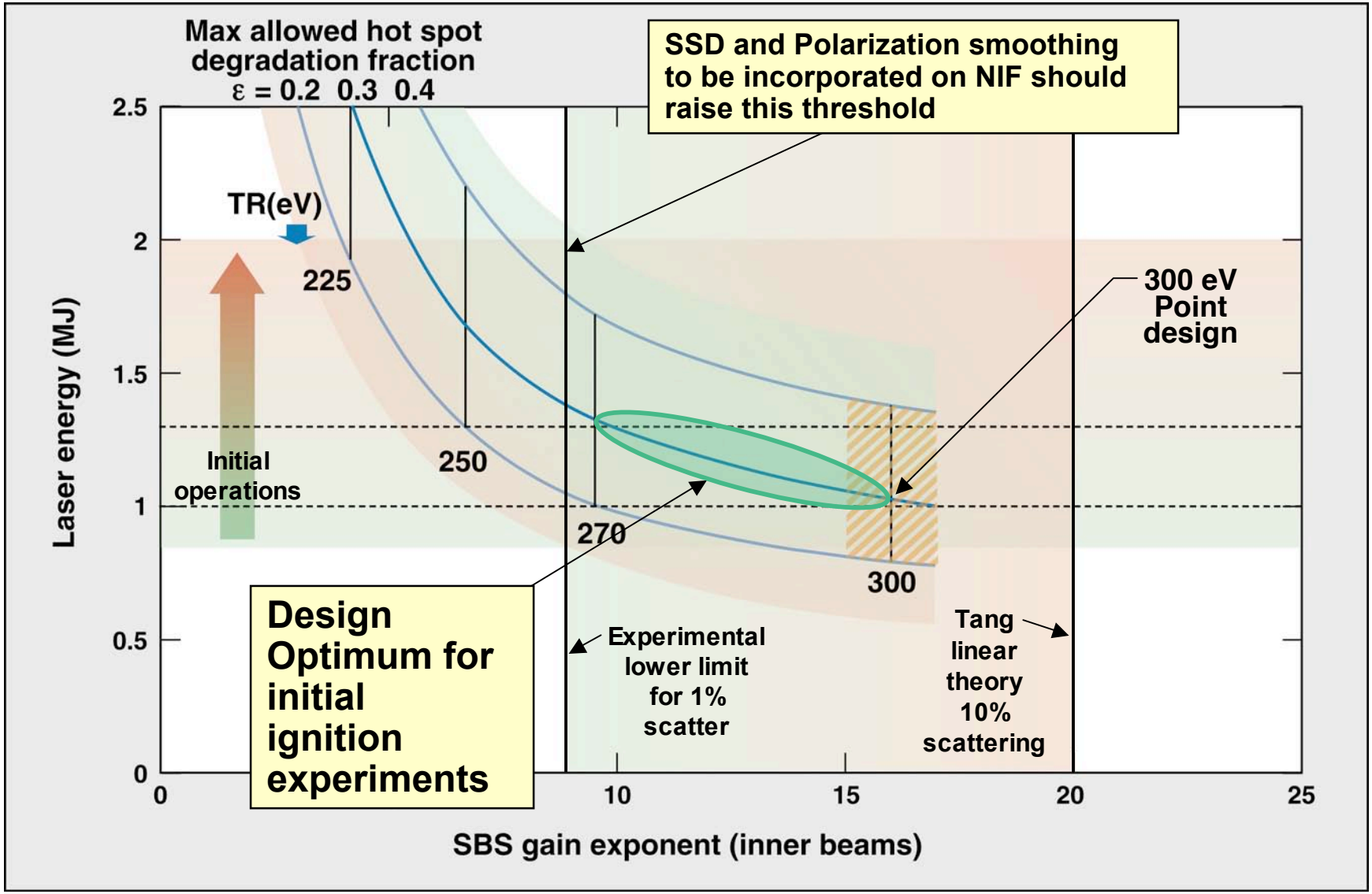

Ignition experiments are organized around Integrated Experiment Teams (IET) and the key diagnostics required for those experiments

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Laser Performance

- pulse shape
- Power balance
- pointing

– SXI - soft x-ray imager for pointing
– SXD - soft x-ray streak for beam timing

Hohlraum Performance

- X-ray drive
- Symmetry

– FABS and NBI - backscattered light
– Dante - thermal x rays
– FFLEX - hard x-rays from high energy electrons
– GSXI - gated low energy x rays for LEH closure
– GXD - gated multi-keV xrays for symmetry

Capsule Performance

- shock timing
- Ablation rates
- Equation of state
- Hydro instability

– VISAR - optical interferometer for shock timing
– SOP - streaked optical emission for shock timing
– Cu collection - ablation dynamics
– Proton spectrometer - ablation dynamics

Ignition

- point design
- implosion diagnostic signatures

– ARC - compton scattering for dense fuel imaging
– Neutron imaging
– Gamma bang time
– NTOF - neutron spectroscopy
– MRS - high resolution neutron spectroscopy
– Protex - knock-on protons for yield
– Cu activation for yield
– Carbon activation - tertiary neutrons
HEXRI - x-ray core

We are developing an ignition program plan which would enable the first ignition experiments in 2009

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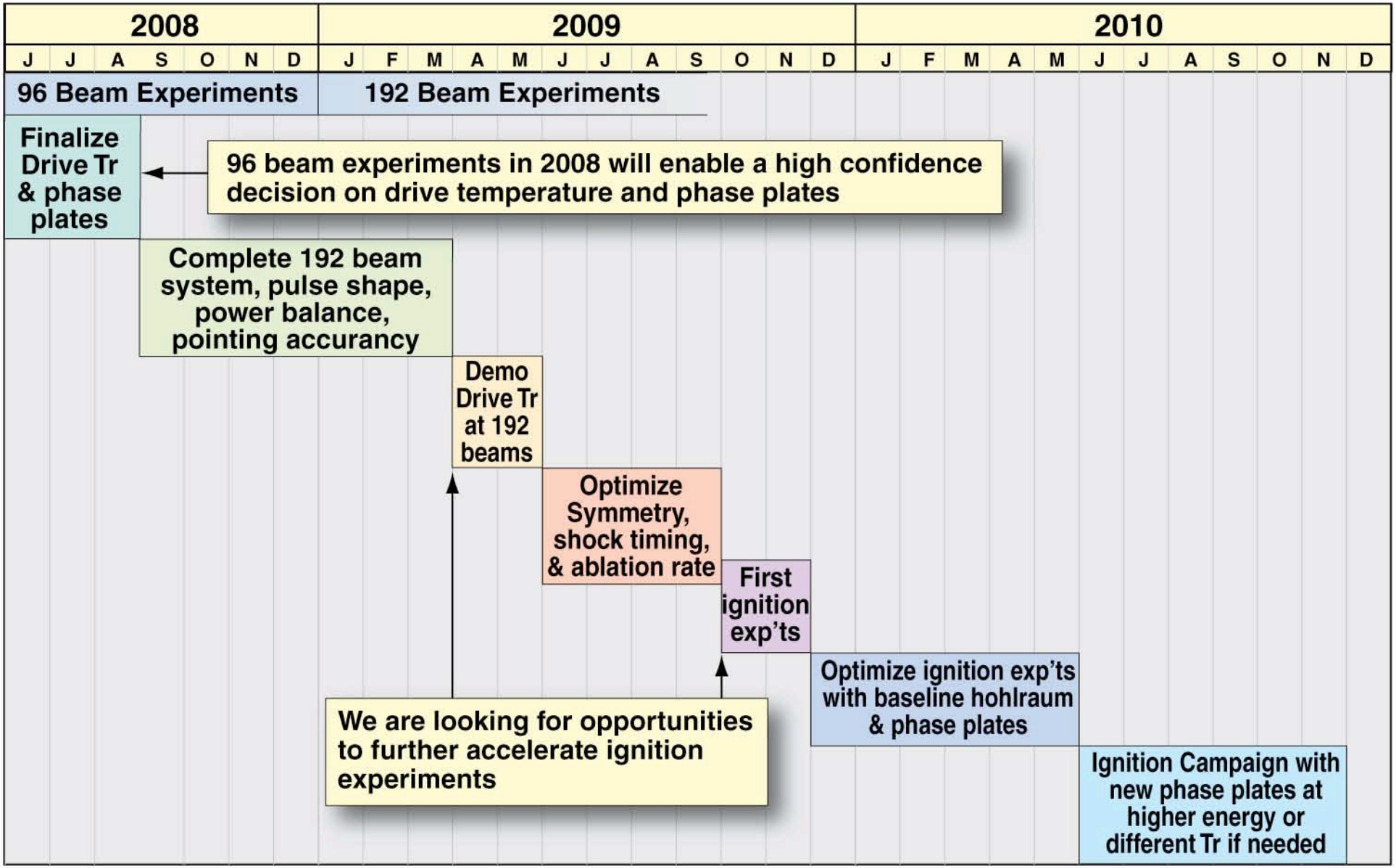

NIF-0107-13150

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

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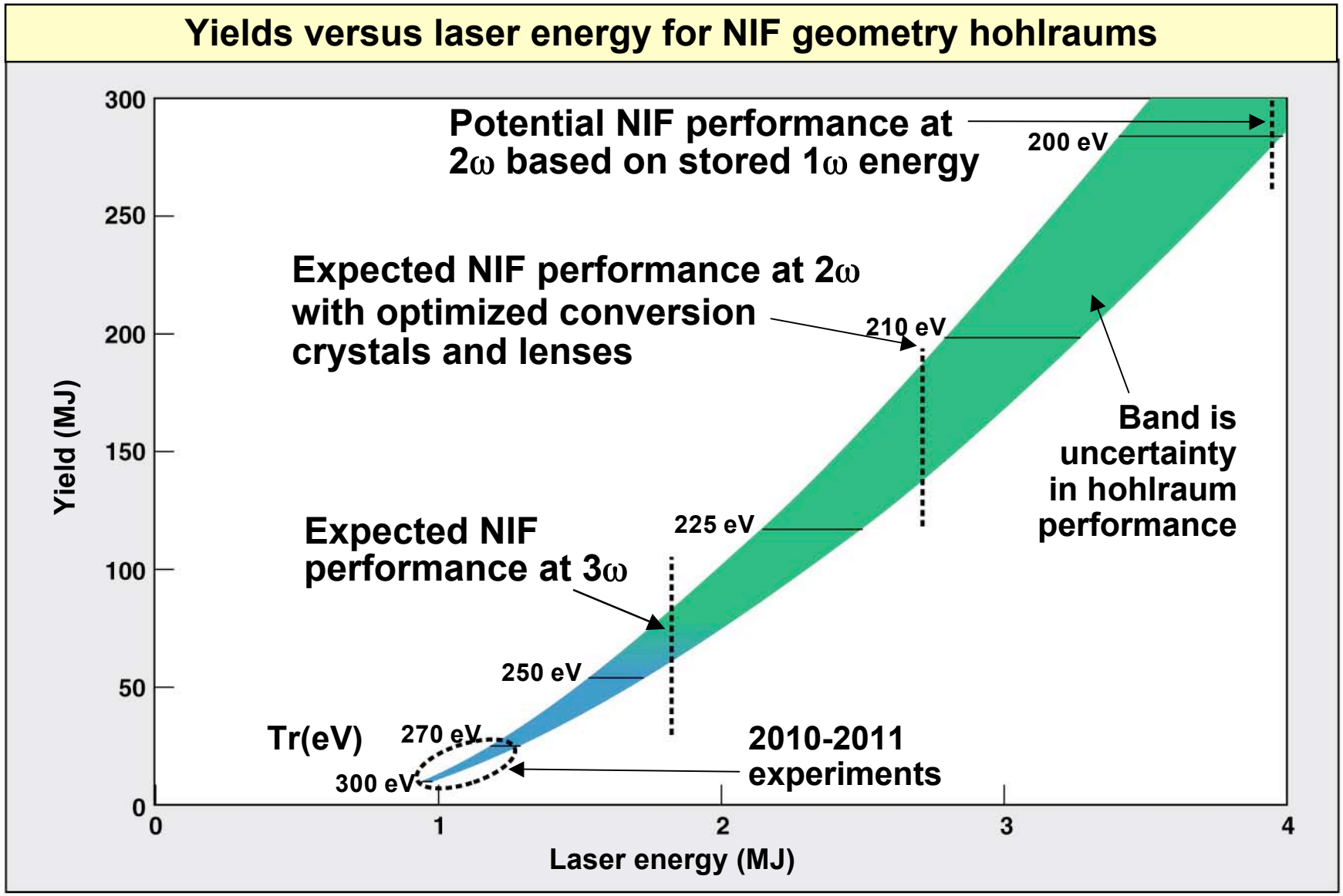

NIF-0107-13186

ARC (Advanced Radiographic Capability) is being implemented on NIF as a major diagnostic for NIC

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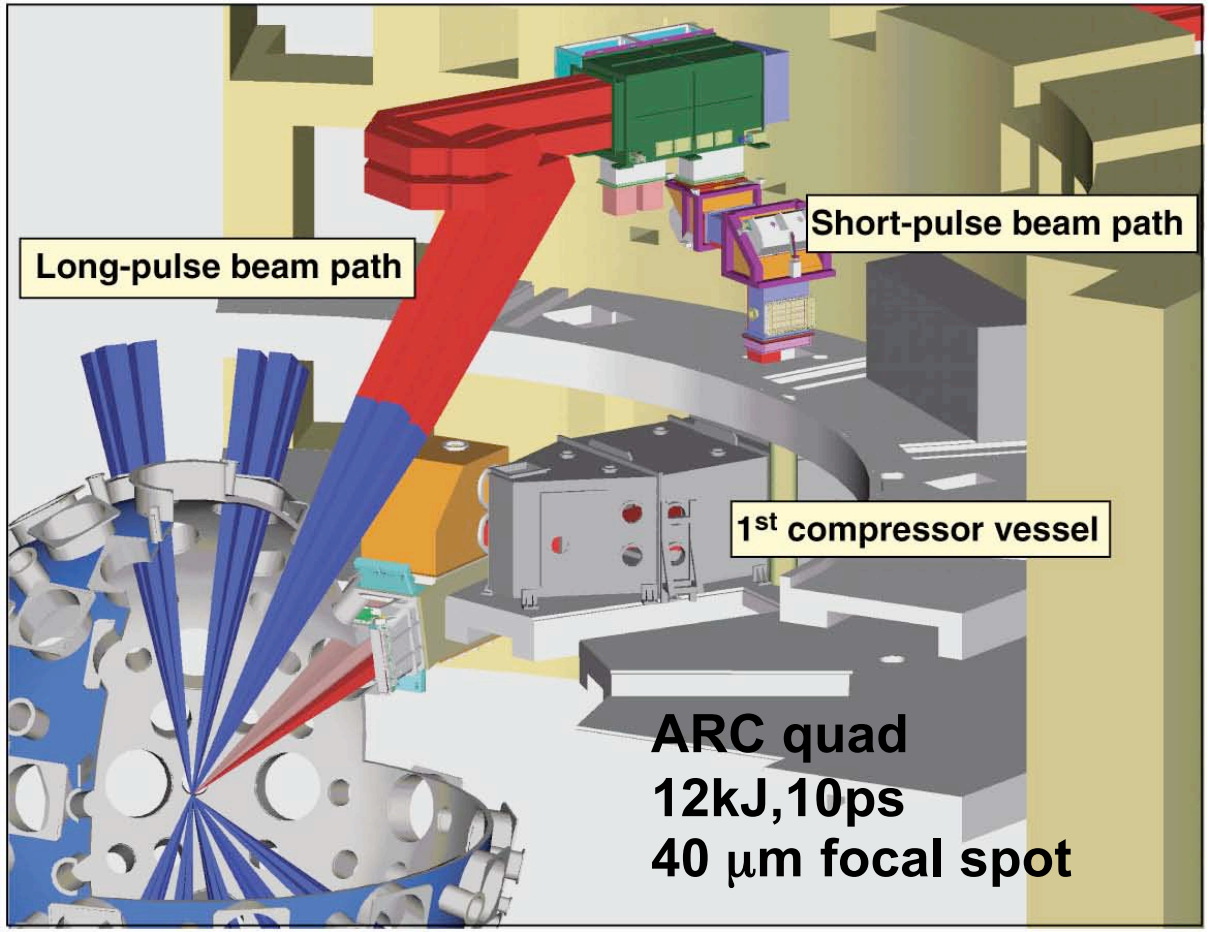

- A "Quad" of NIF beams is compressed to deliver a 1-10 ps pulse
- Uses include backlighter for dense cold fuel in ignition targets and a variety of high optical depth HEDP targets
- NIF can provide a full scale high gain compressed fuel assembly for fast ignition
- Up to 5 short pulse quads could be deployed on NIF for fast ignition

All of the pieces for ignition are almost in place

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