NATIONAL IGNITION FACILITY

The National Ignition Facility: Exploring ICF Burning Plasmas in the Laboratory

Presentation to US-Japan Workshop

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March 21-22, 2005

SCIENCE IN THE NATIONAL INTEREST

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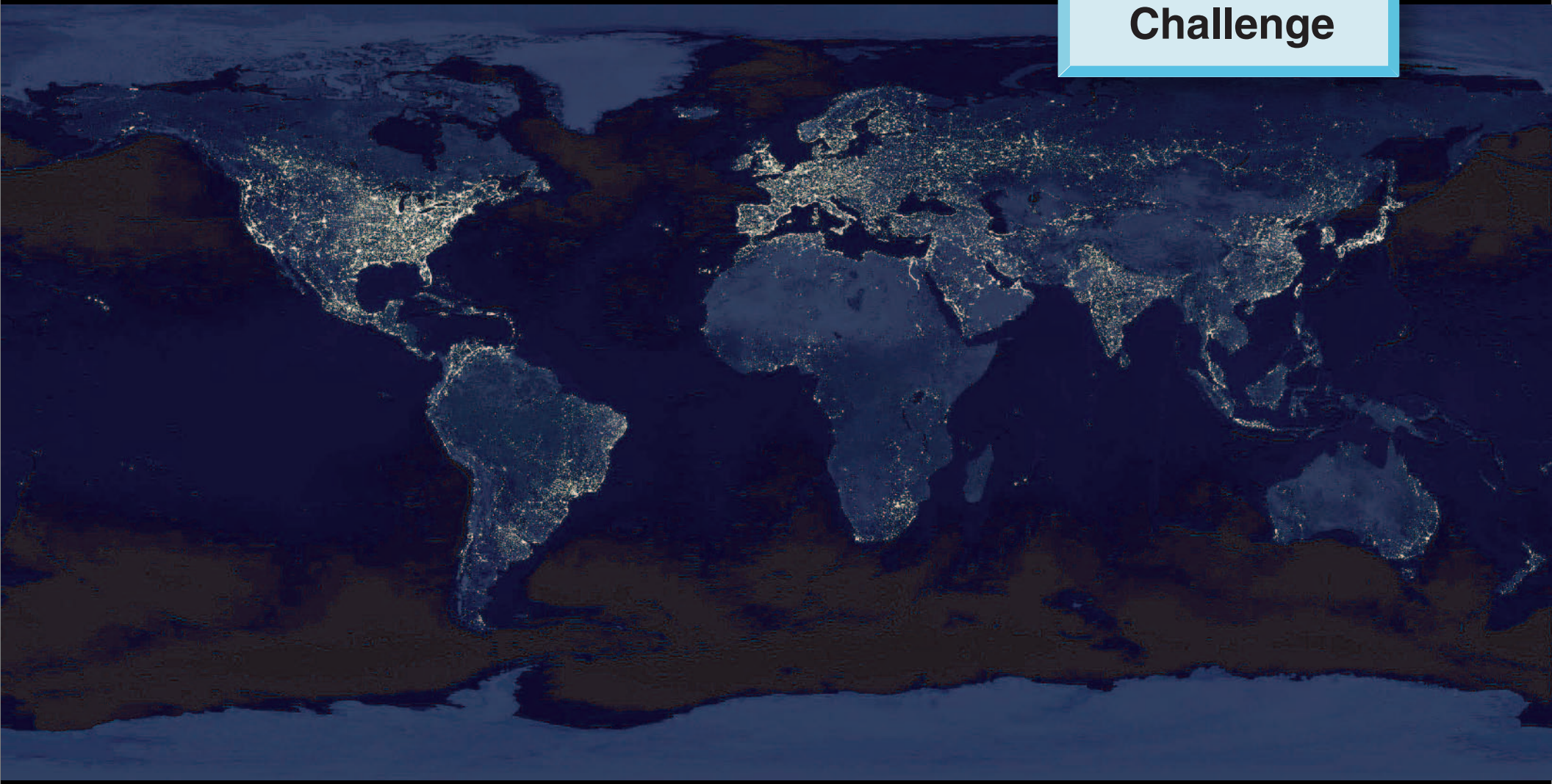
P8584

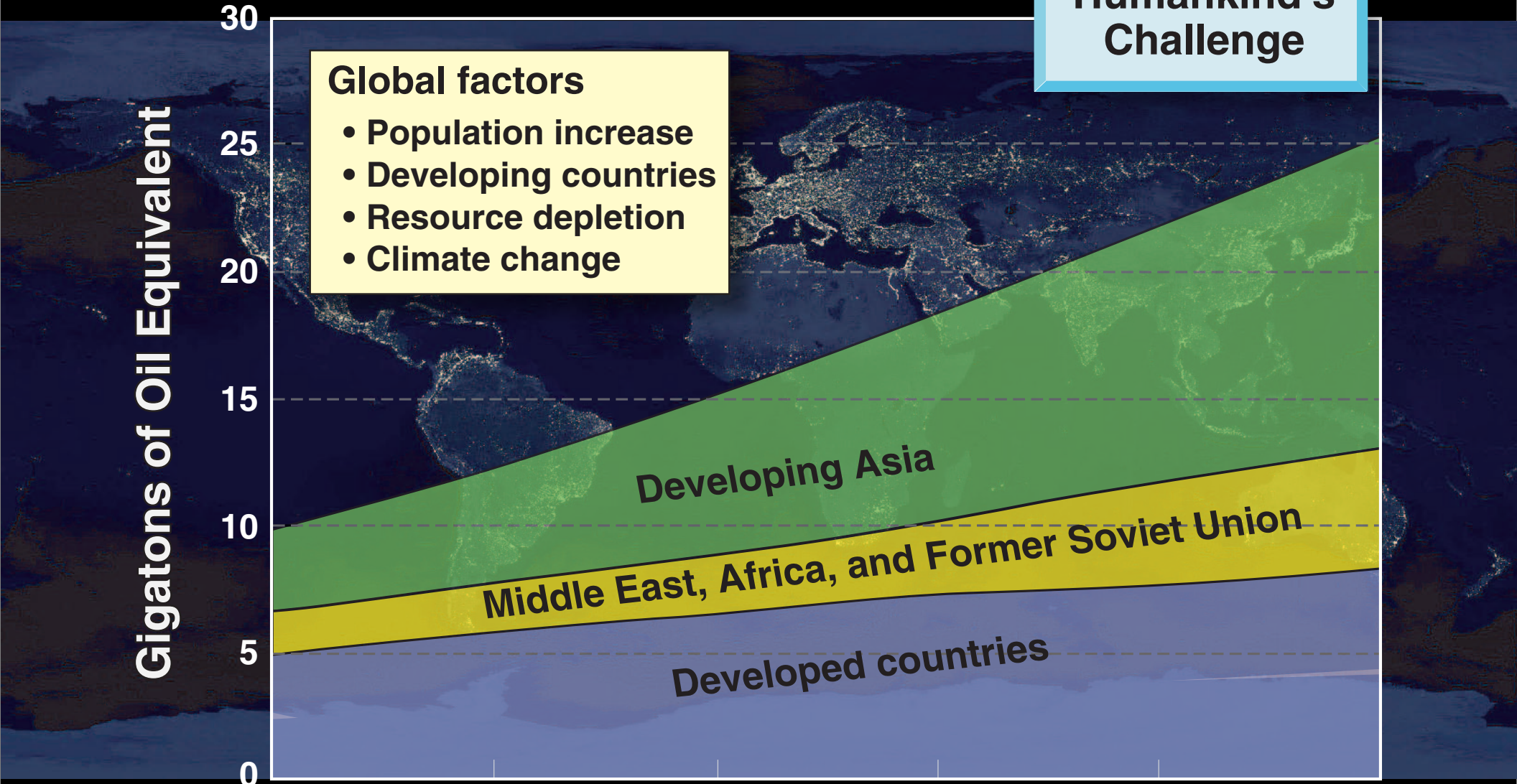
Clean Energy: Humankind's Challenge



NIF-0205-10331
15EIM/sb

P8434

Clean Energy: Humankind's Challenge



Fusion energy may be a future energy option

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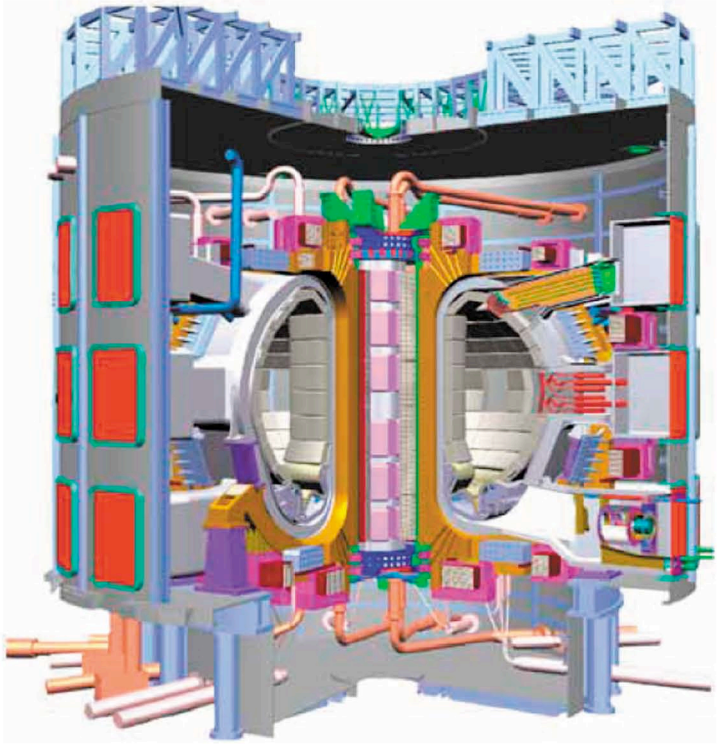
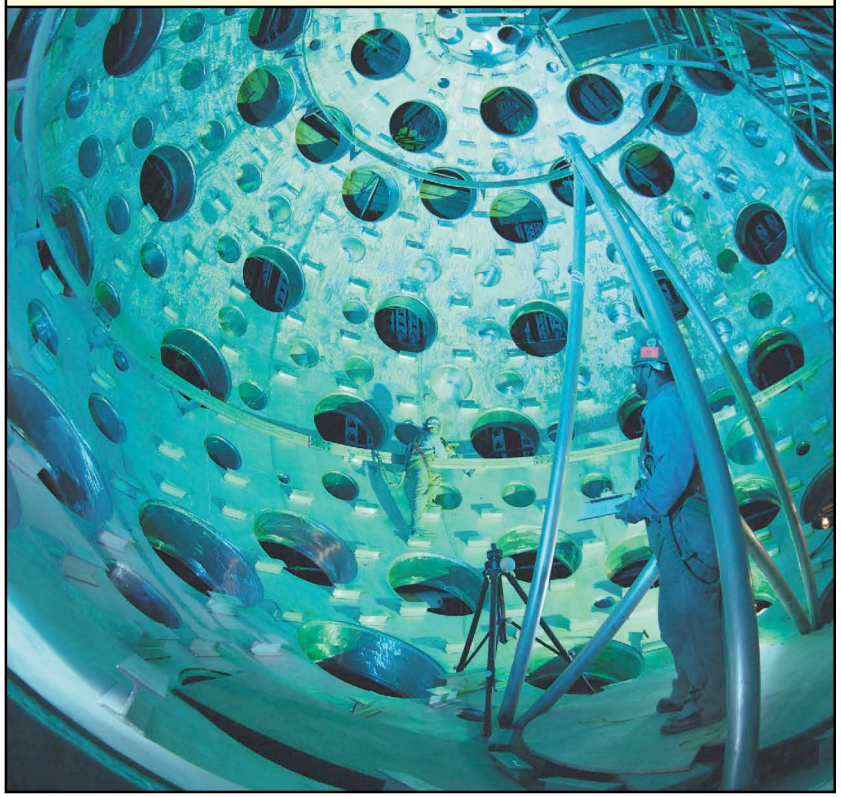
Magnetic Fusion Energy



Inertial Fusion Energy



Biggest challenge is making it safe, reliable, and cost effective


Could we build a miniature sun on earth?

NIF-1104-09783
17EIM/tr

P7481

NIF-0105-10118
21EIM/tr

P8134

NIF-1104-09784
17EIM/tr

P7488

Laser Bay 2 Build

Laser Bay 2 Flyover

192 beam, 1.8 MJ, laser organized into “bays,” “clusters”, “bundles”, and “quads”

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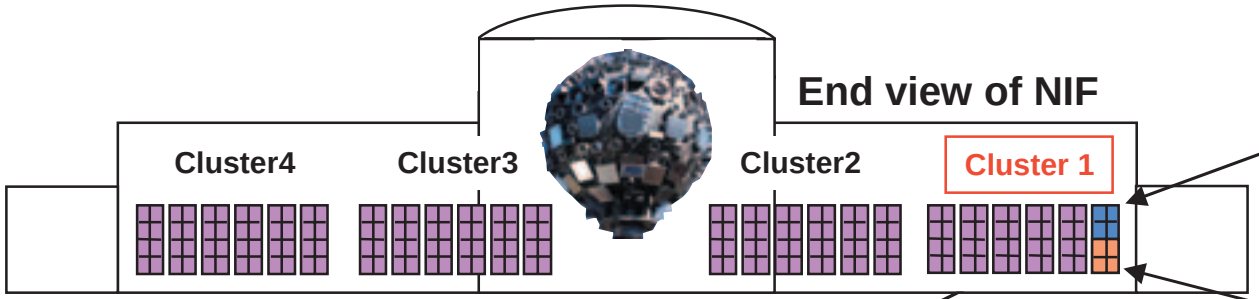
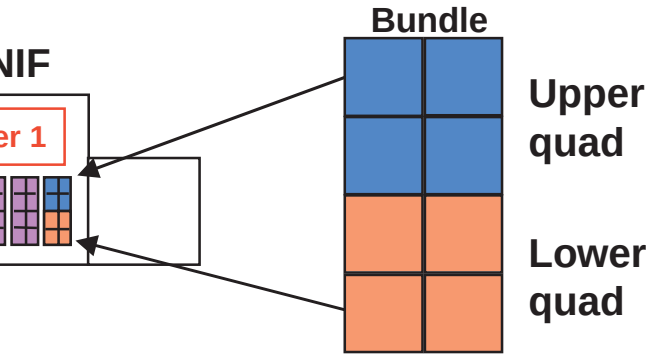
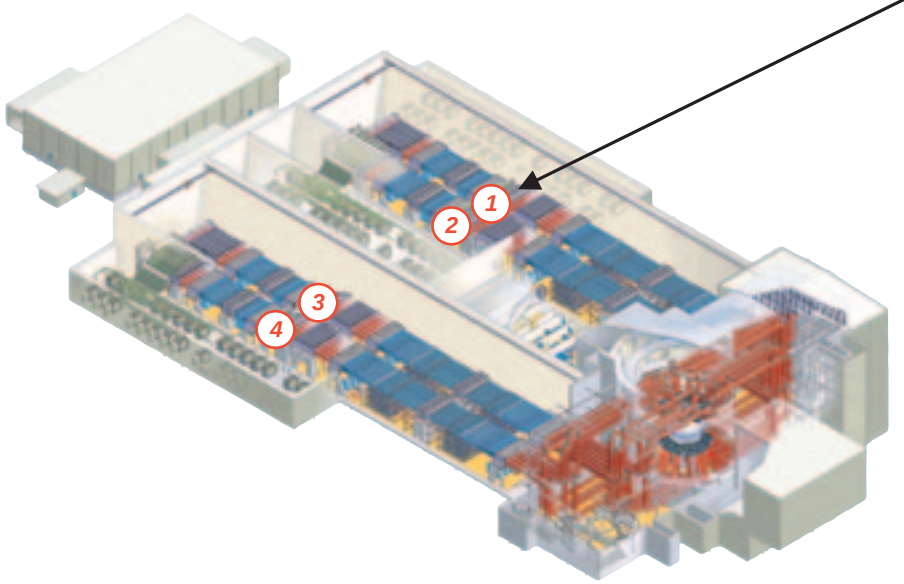
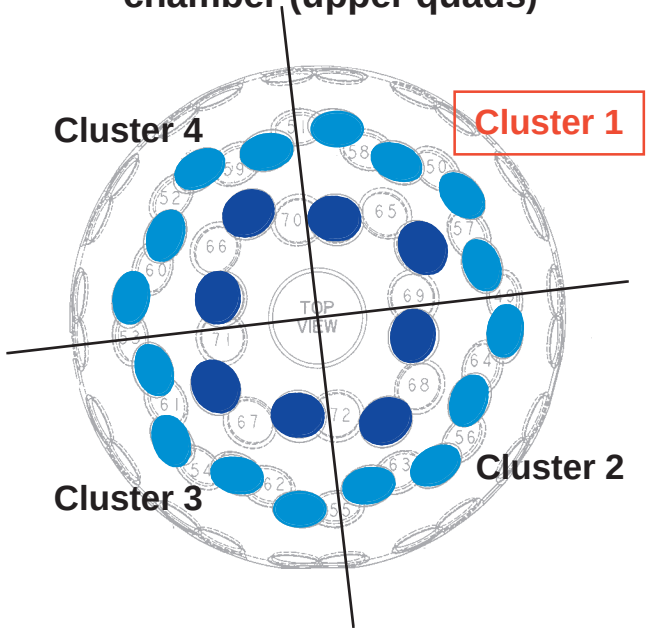


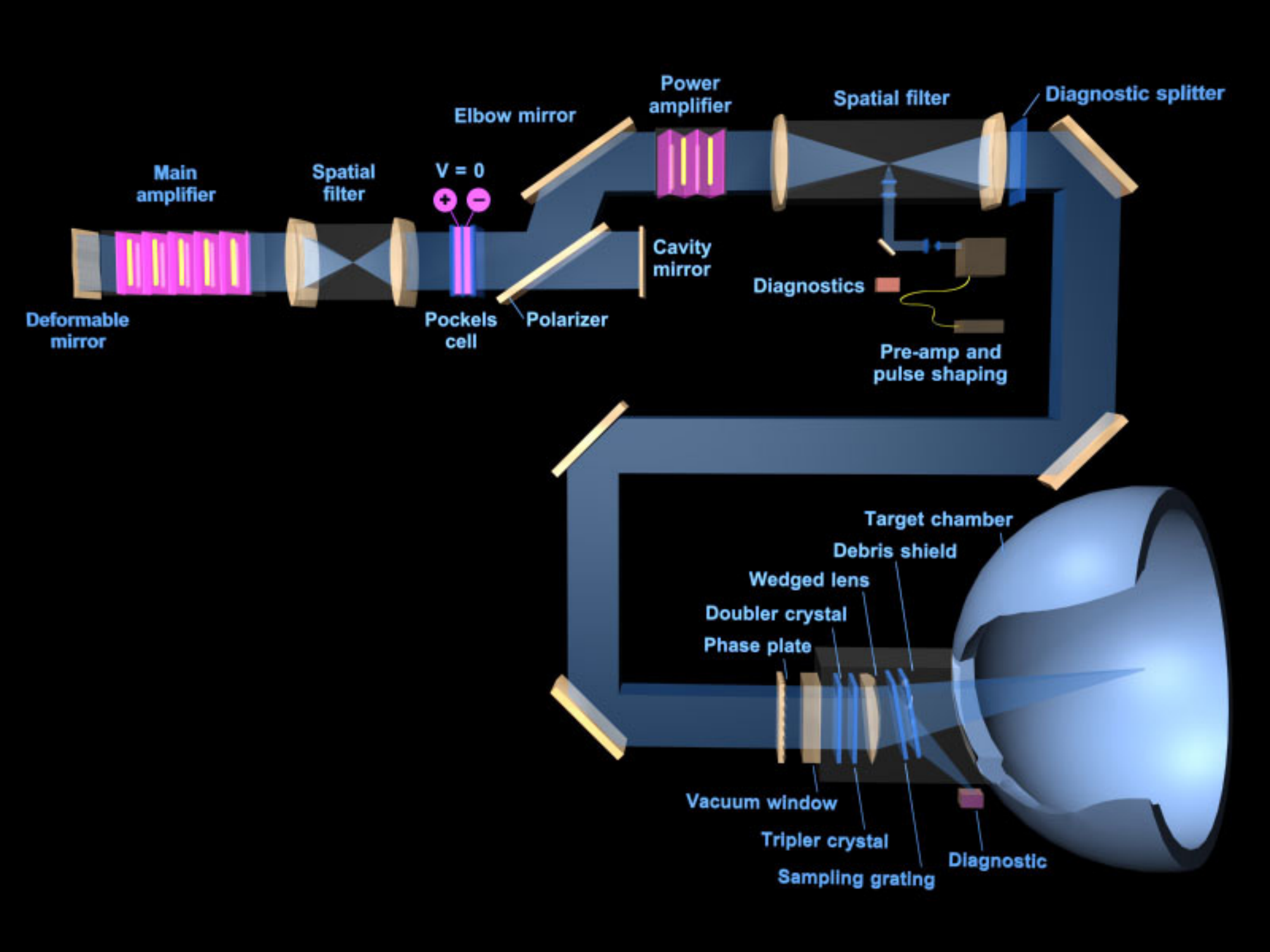




Top view of target chamber (upper quads)



“Quads” are the basic building blocks of a NIF experiment, 4 beams with the same pulse shape and time delay


Power amplifier
Spatial filter
Diagnostic splitter
Elbow mirror
Main amplifier
Spatial filter
V = 0
Cavity mirror
Diagnostics
Deformable mirror
Pockels cell
Polarizer
Pre-amp and pulse shaping
Target chamber
Debris shield
Wedged lens
Doubler crystal
Phase plate
Vacuum window
Tripler crystal
Sampling grating
Diagnostic

NIF 1ω laser exceeds power and energy requirements for entire operational parameter space

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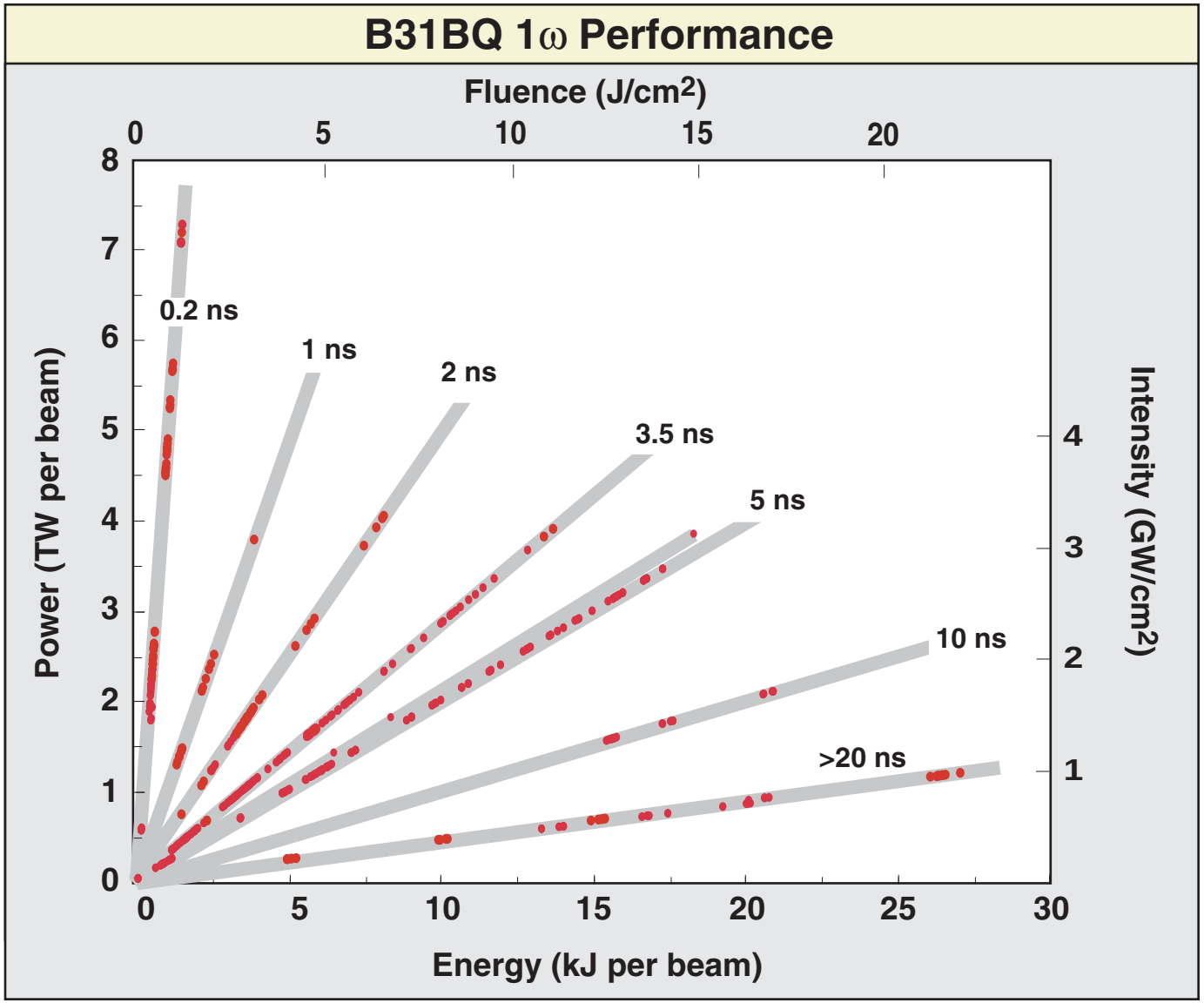

Design goals for 1ω energy and power exceeded with high overall beam quality

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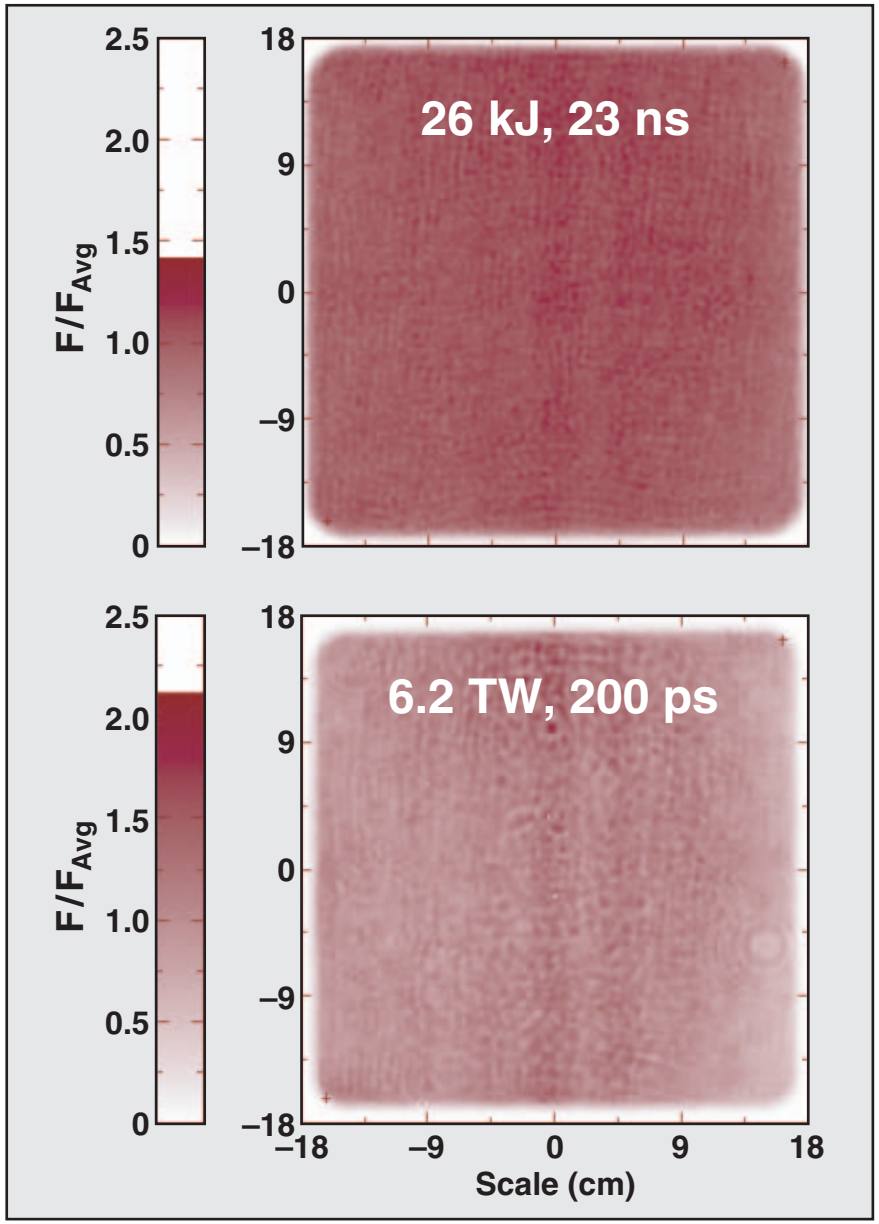
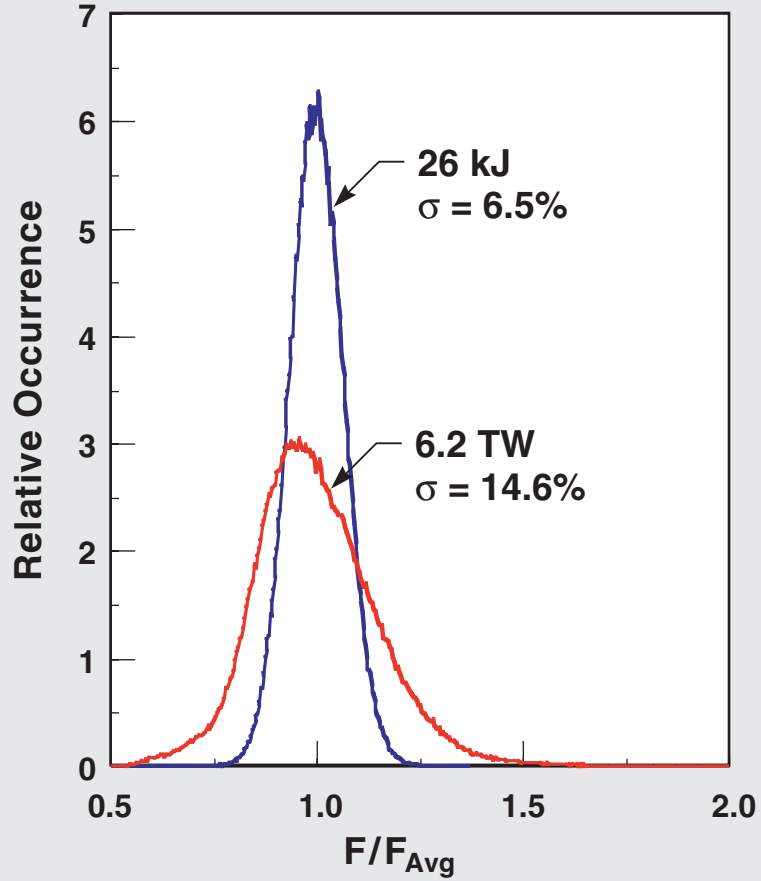


Fluence Distributions Measured Over Central 30 cm



2ω and 3ω performance

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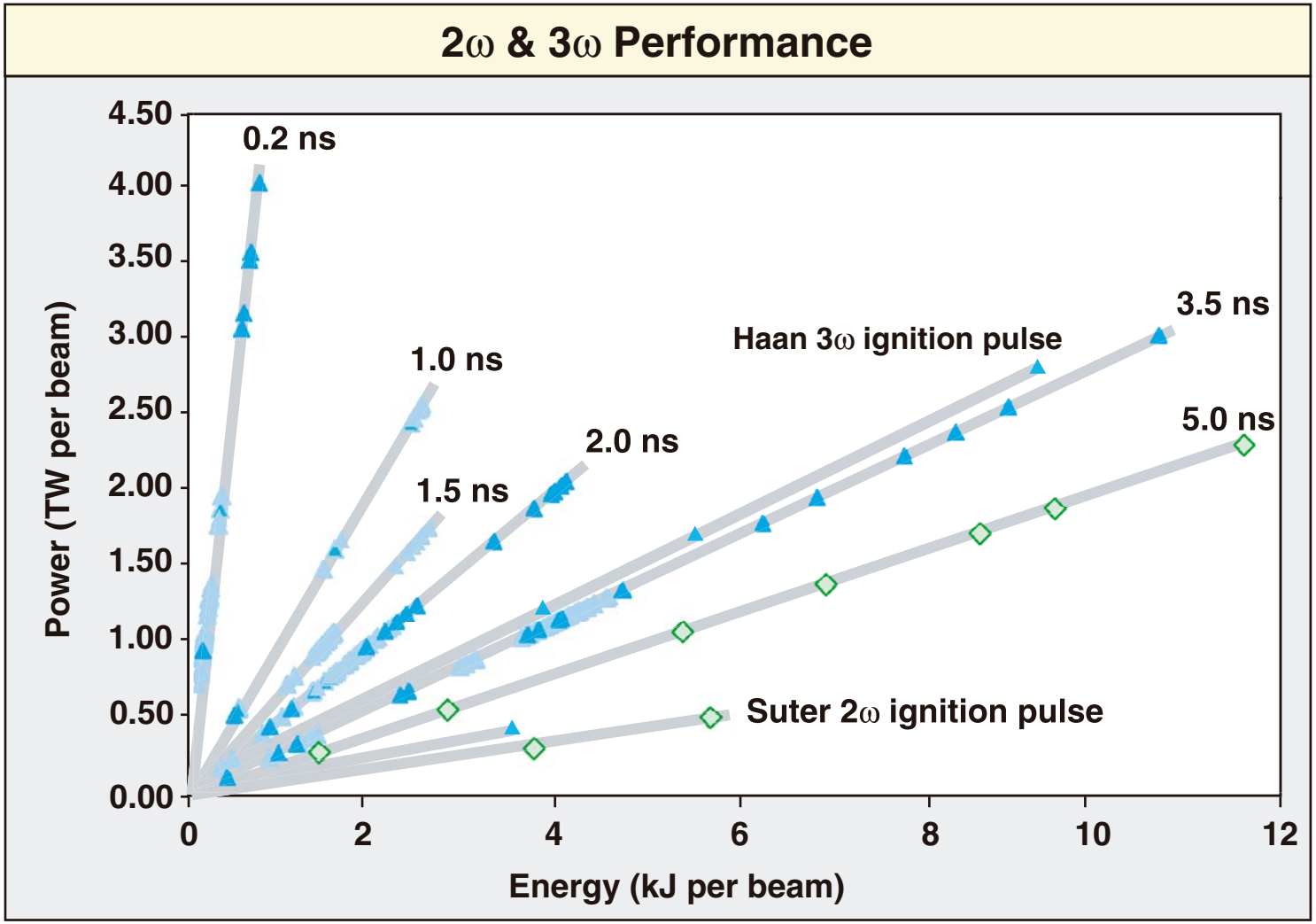

2ω and 3ω beamline energies are highest ever achieved

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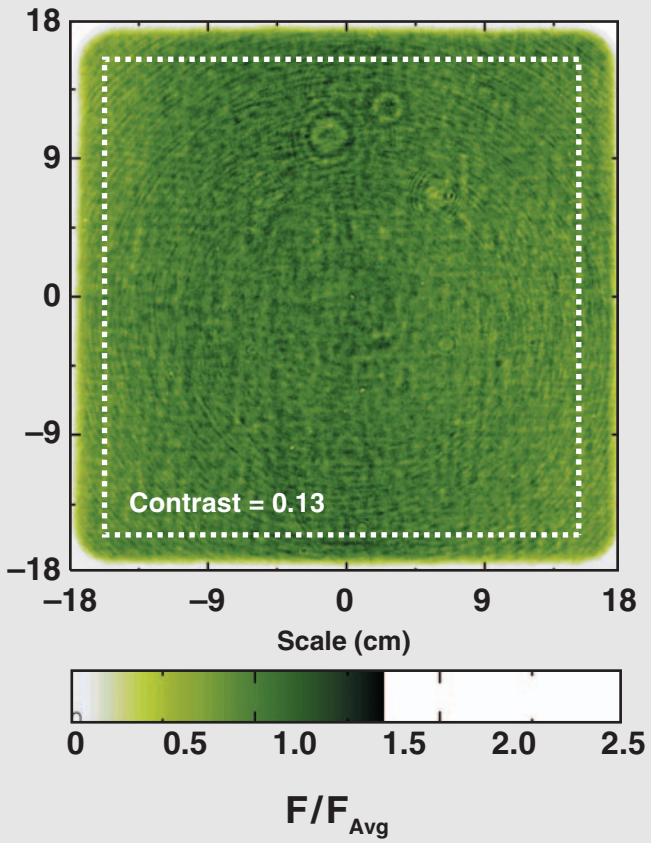
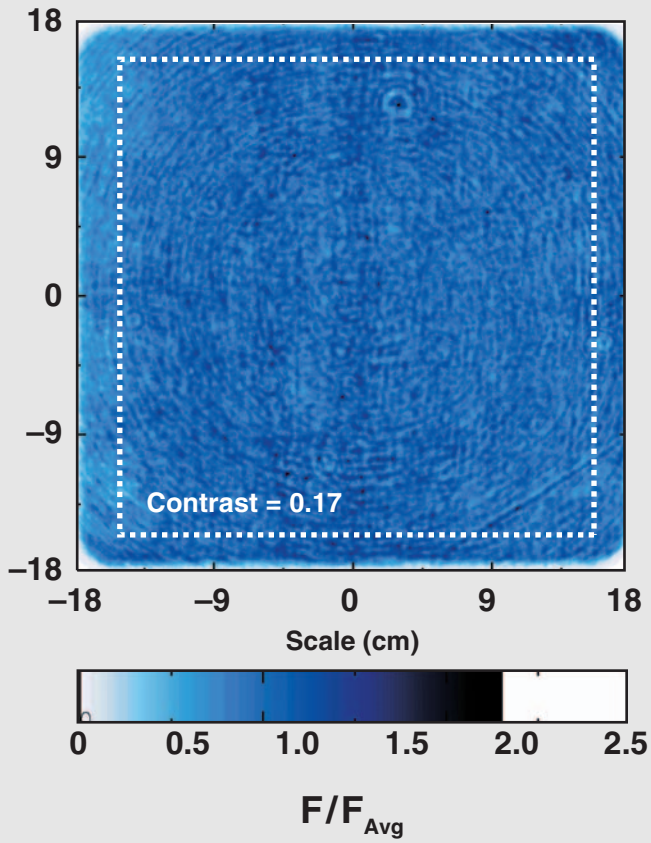
11.4 kJ 2ω, 5 ns



10.4 kJ 3ω, 3.5 ns



Each beam of NIF is 10x energy of other operational lasers world wide

Shot cooling periods as short as 1.5 hours have been demonstrated on NIF

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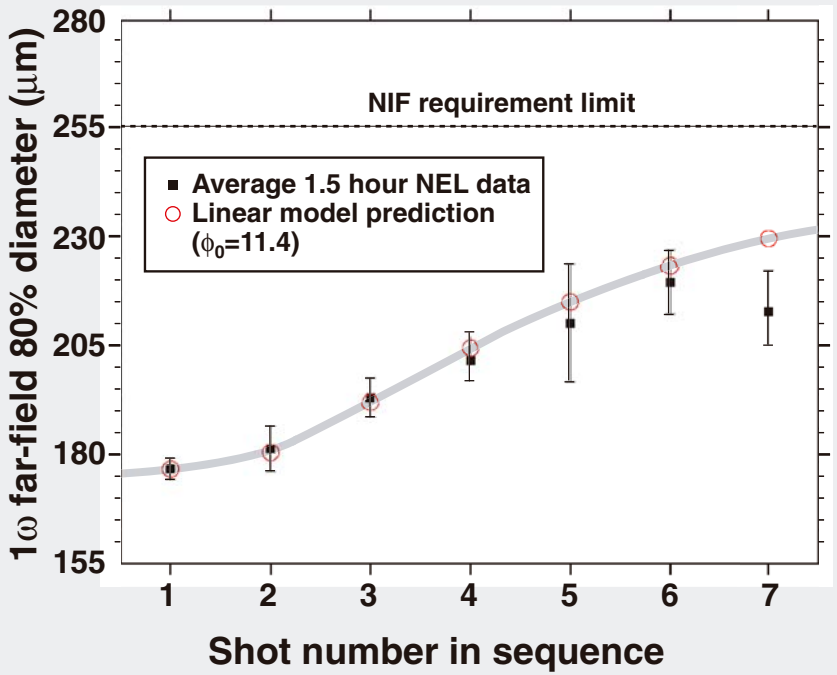
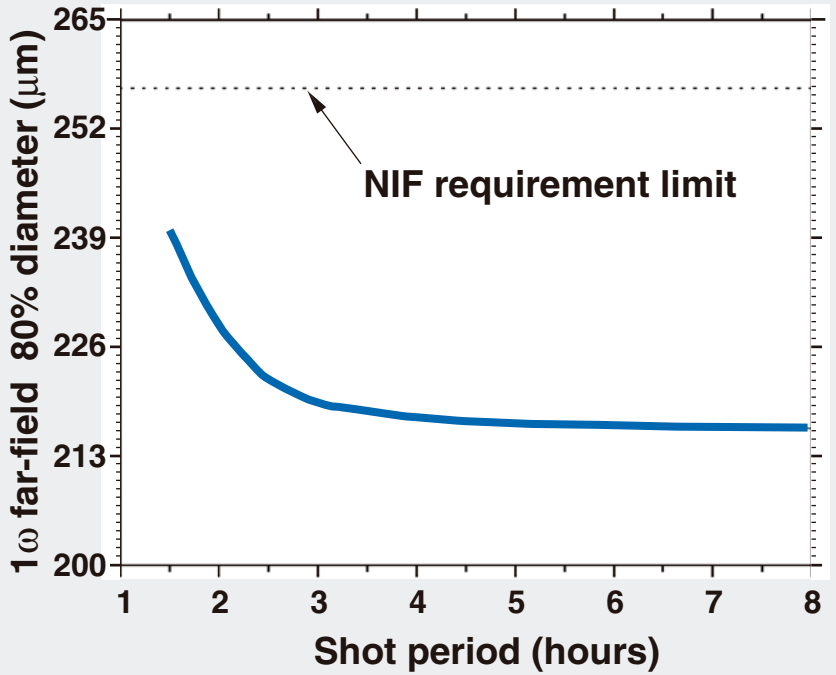
CFD Calculations Fit our Measured Focal Spot Size Data even at 1.5h Shot Rate



Shot Cooling Periods are Calculated to only Marginally Increase Focal Spot Size

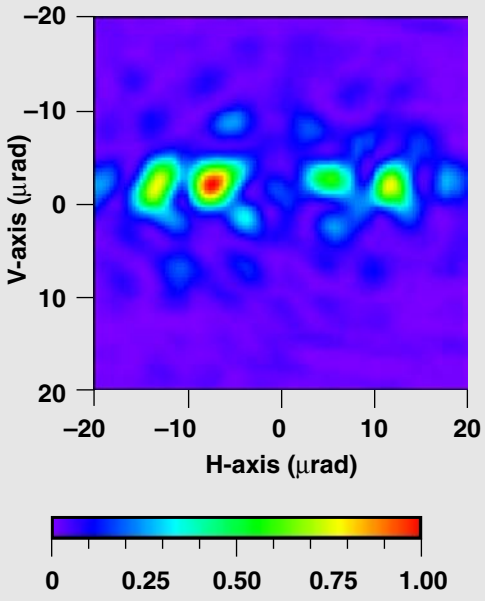


Short shot cycles appear practical even for the most demanding users

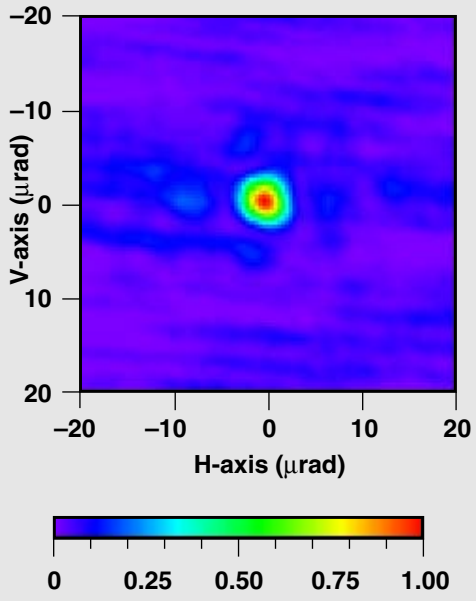
Adaptive wavefront correction of Beamlet produced ~2× diffraction limited focal spot

39 actuator deformable mirror corrects static and dynamic pump induced wavefront distortion

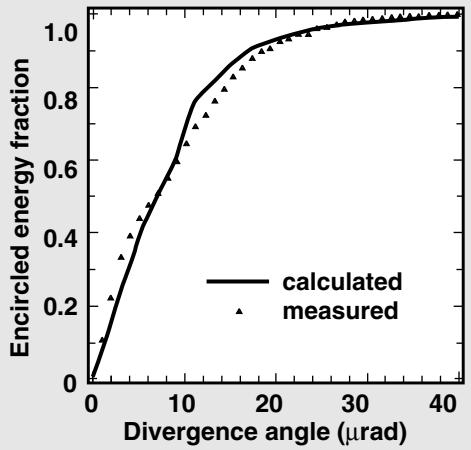
Without pump-induced precorrection



With full correction



Radial integral of 1ω far field spot distribution



Position, timing accuracy, and stability

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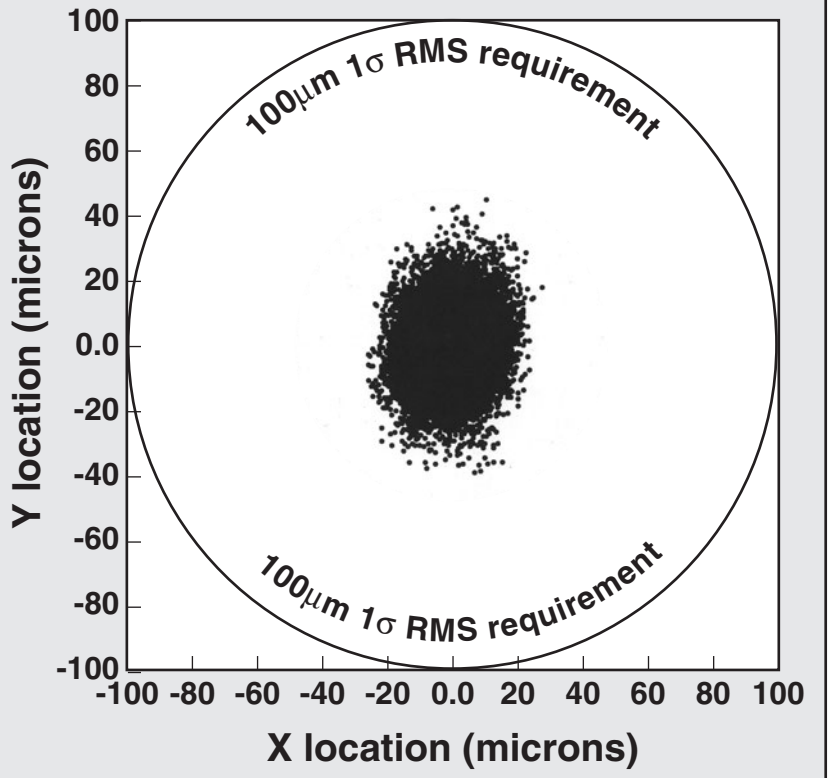
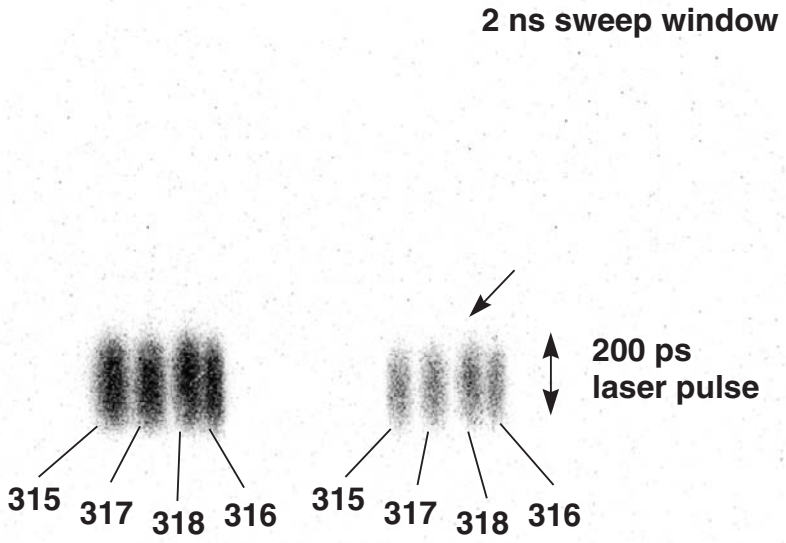
Stability Scatter Plot (8 hours)



Beam timing adjusted to within 6 ps (rms)



NIF Project Completion Criteria: Laser Performance

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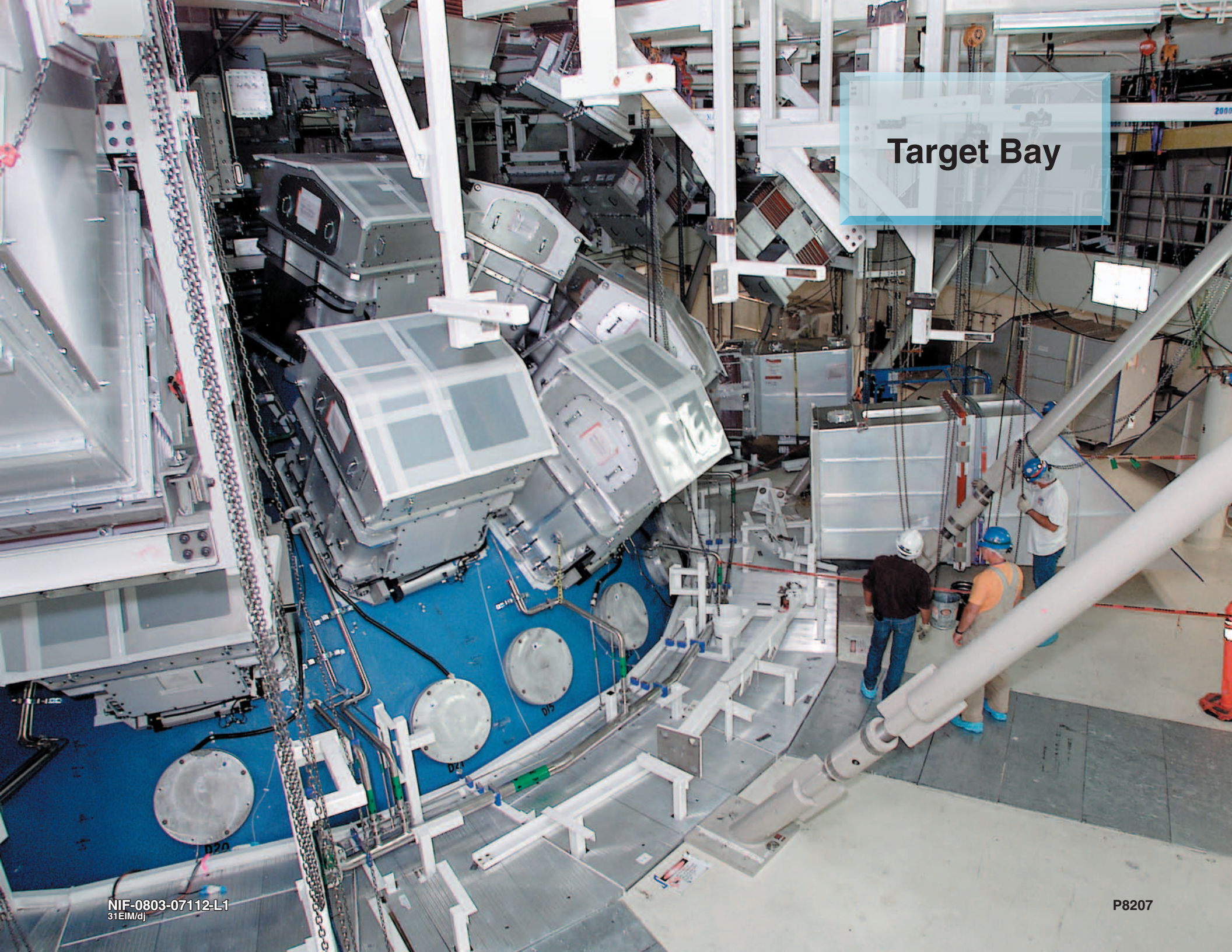
Specification	96 Beam Performance	Single Bundle Performance	Current Beamline Status
Pulse Energy	500 kJ (1000 kJ)	75 kJ (83 kJ)	✓
Peak Power	200 TW (400 TW)	21 TW (32 TW)	✓
Wavelength	.35 ∝m (.35 & .53 ∝m)	.35 ∝m (.35 & .53 ∝m)	✓
Positioning Accuracy	100 ∝m RMS (30 ∝m)	100 ∝m RMS (30 ∝m)	✓
Pulse Duration	20 ns (0.2 – 23 ns)	20 ns (0.2 – 23 ns)	✓
Pulse Dynamic Range	>25:1 (108:1)	50:1 (108:1)	✓
Pulse Spot Size	600 ∝m (140 ∝m – 750 ∝m)	600 ∝m (140 – 750 ∝m)	✓
Pre-pulse power	$<10^8$ W/cm^2 ($<<10^8$ W/cm^2)	$<4 \cdot 10^6$ W/cm^2 ($<<4 \cdot 10^6$)	✓
Cycle Time	8 hours max between full system shots (<4 h)	8 hours max between full system shots (<4 h)	✓

- On a beamline basis, NIF has demonstrated operation at:
  - — All Project Completion Criteria
  - — Long-term Functional Requirements and Primary Criteria
- NIF has fired 384 full system shots

Target Chamber in Target Bay

NIF-0105-10163
31EIM/dj

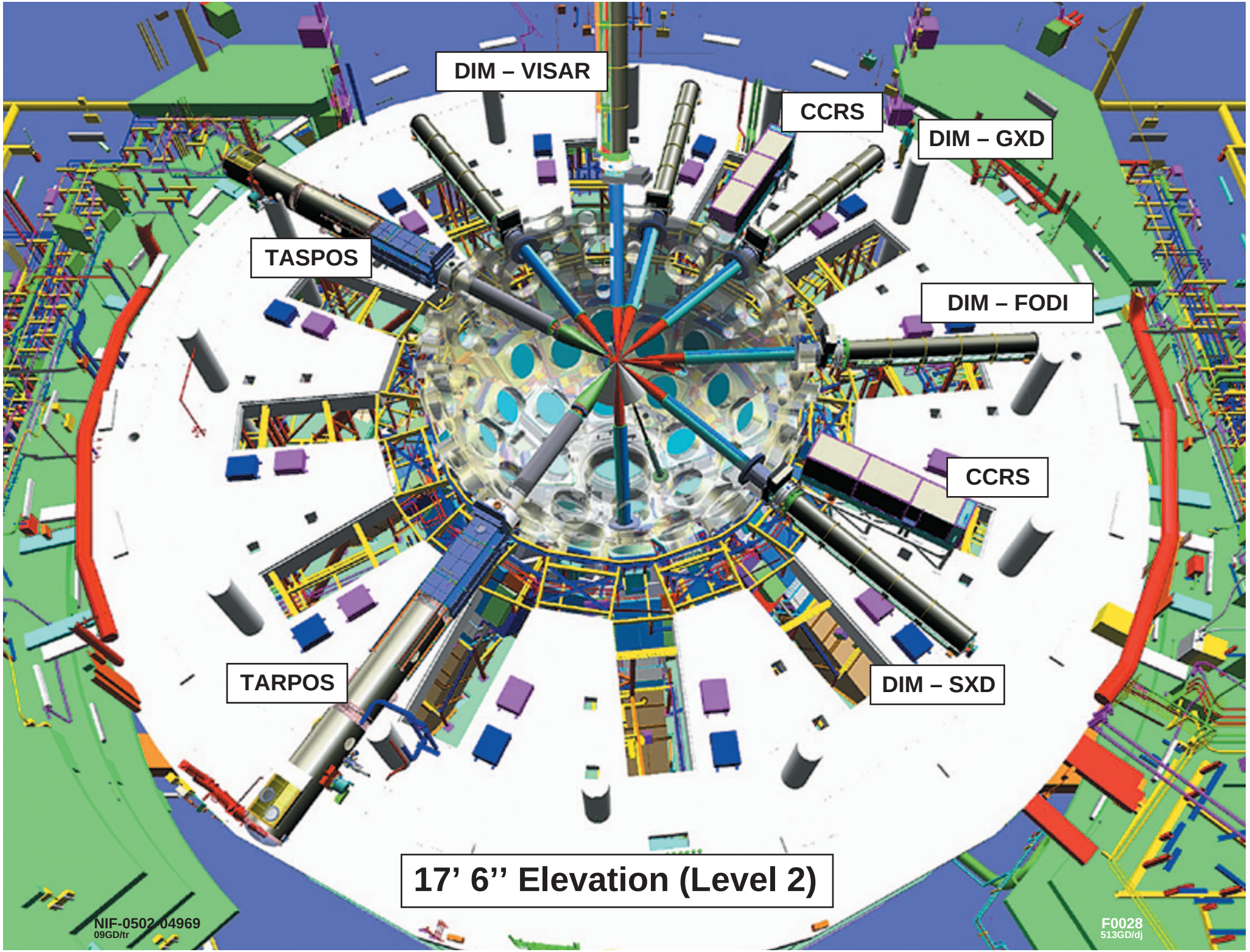
P8195


Target Bay
NIF-0803-07112-L1
31EIM/dj
P8207

NIF-0501-02172

X2235


Systems Engineer
Positioner
Target Alignment Sensor
NIF-0703-07087
P5924


DIM – VISAR
CCRS
DIM – GXD
TASPOS
DIM – FODI
CCRS
TARPOS
DIM – SXD
17’ 6’’ Elevation (Level 2)
NIF-0502-04969
09GD/tr
F0028
513GD/dj

The first four NIF beamlines have been commissioned to the center of the target chamber

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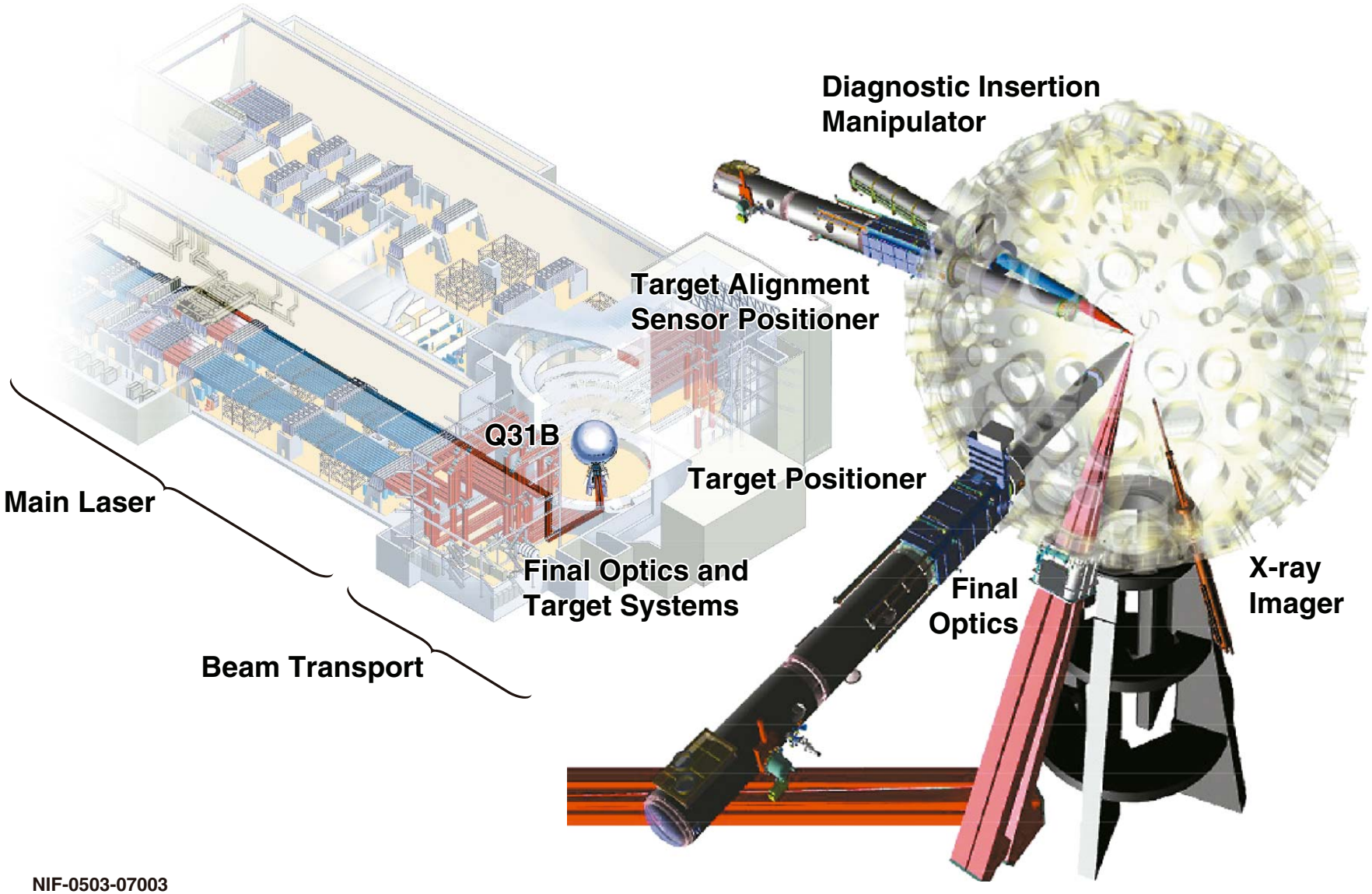
End-to-end functionality of all major subsystems demonstrated



We are developing NIF into the premier facility for understanding matter at extreme conditions

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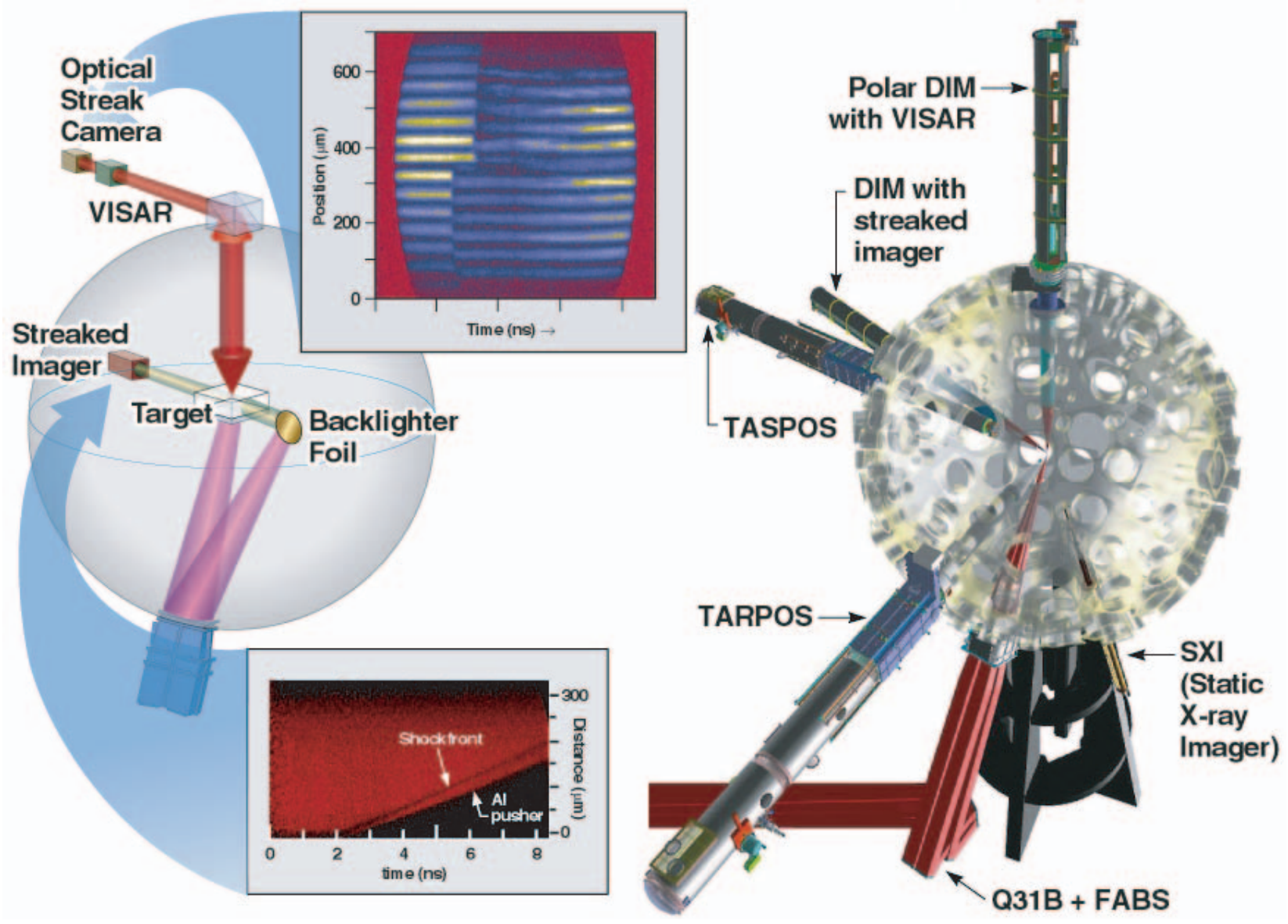

A series of 2D and 3D jet features were measured to benchmark ASCI radiation hydro codes

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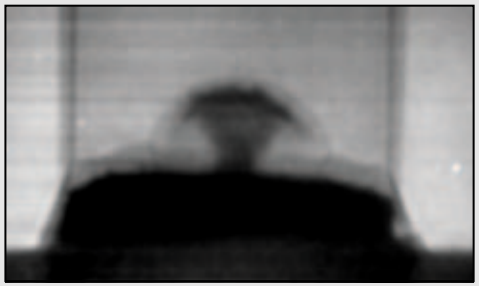
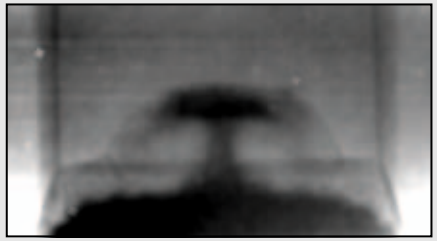
2D Features



15 ns

21 ns



21 ns

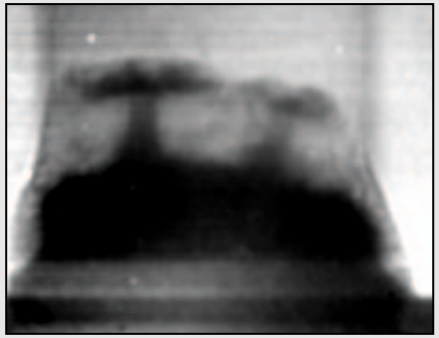
Time series measure hydrodynamic evolution

Duplicate shots measure repeatable hydrodynamic evolution

3D Features

Orthogonal 15 ns

Asymmetric 15 ns



Asymmetric 21 ns

Gated x-ray imaging measures the beam transport through the target

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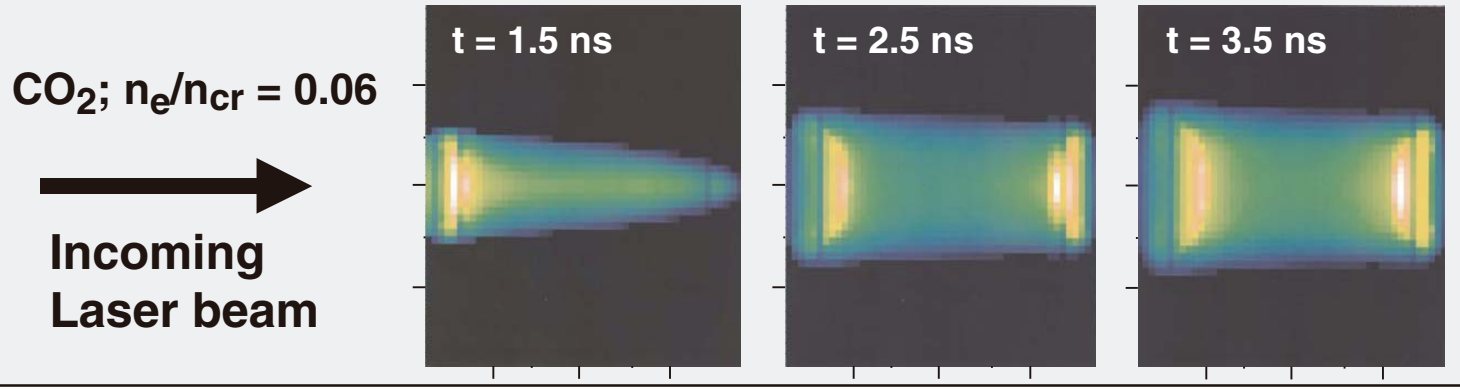
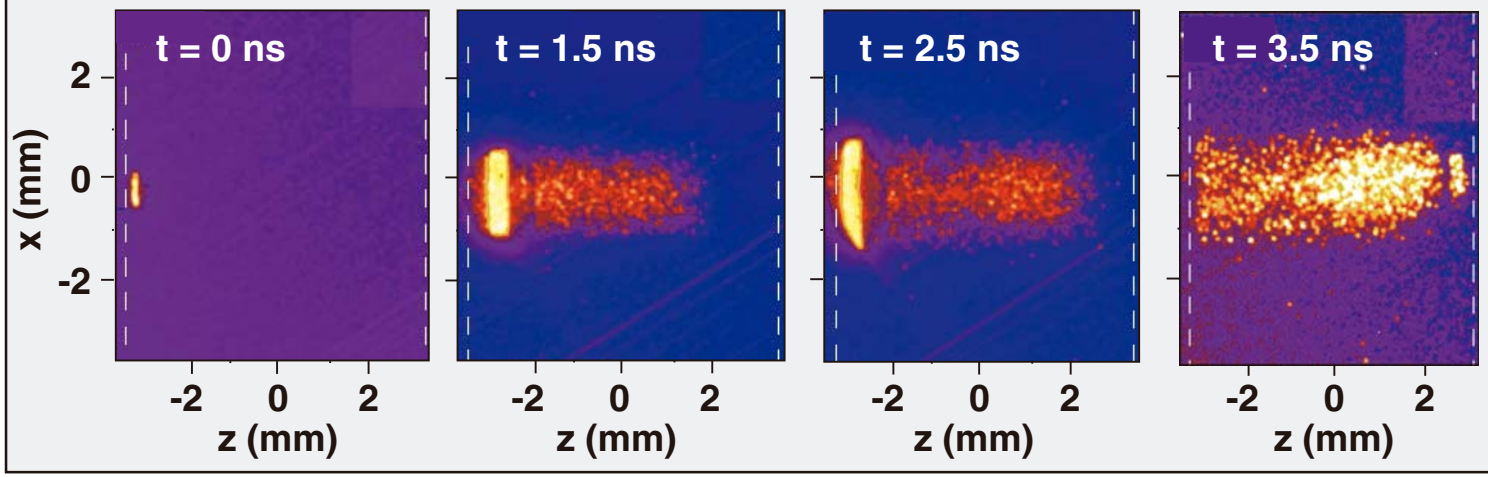
LASNEX Calculation for 3.5 keV X-rays



Gated X-ray imaging (3.5 keV filtering)



We observe approximate agreement between the experimental data and the LASNEX calculations

NIF is ready to deliver the next generation of High Energy Density Physics Experimental Capability

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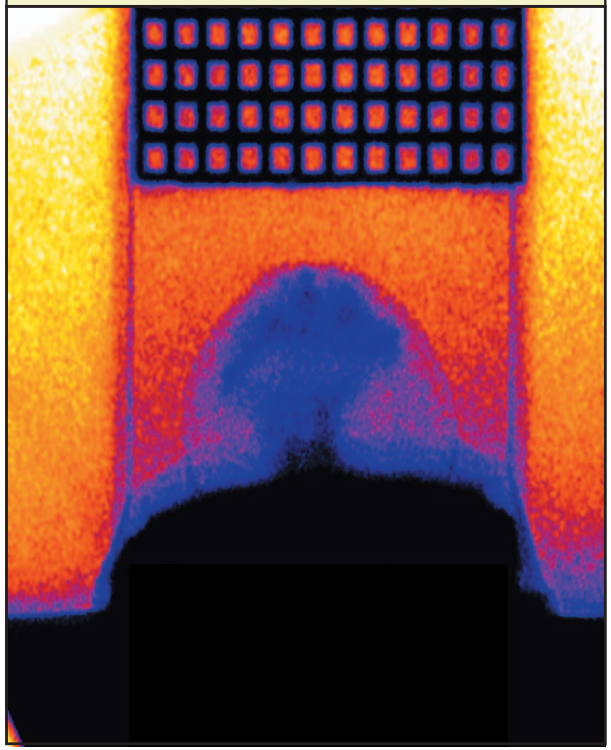
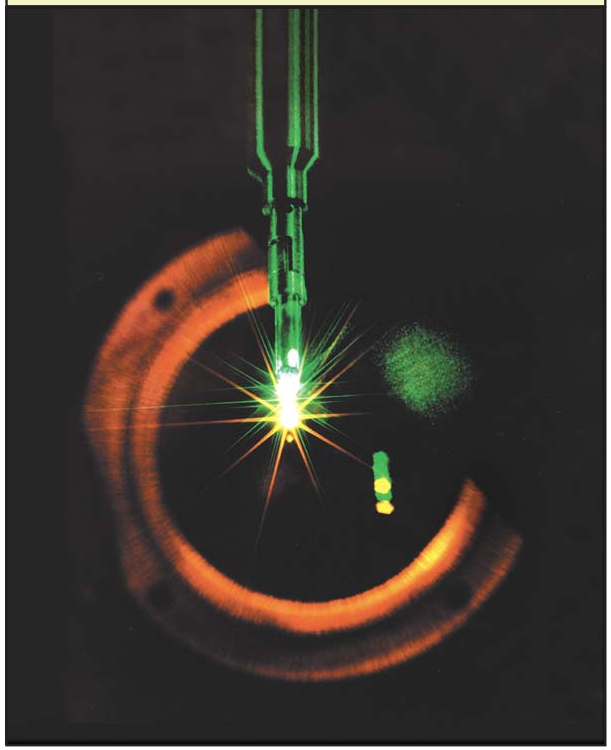
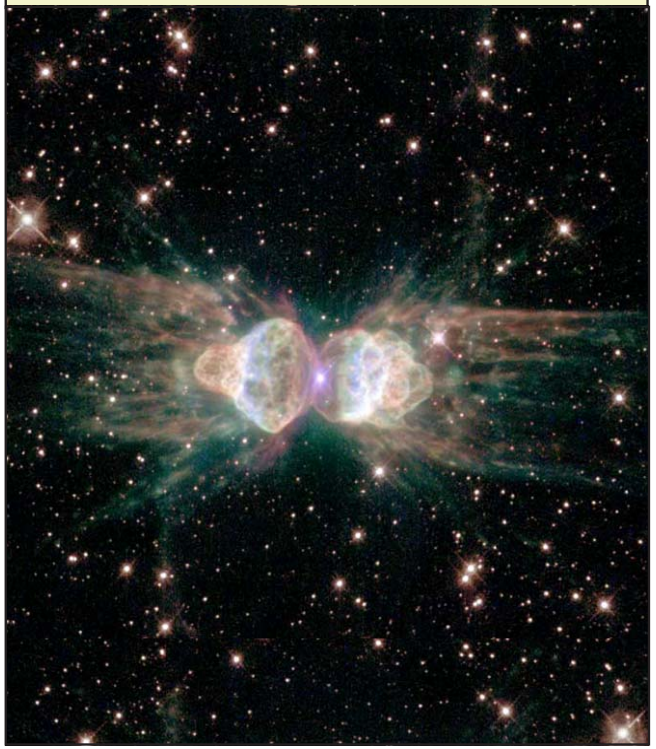
High Energy Density Physics



Fusion Ignition



Basic Science



Is NIF a precursor to an IFE plant?

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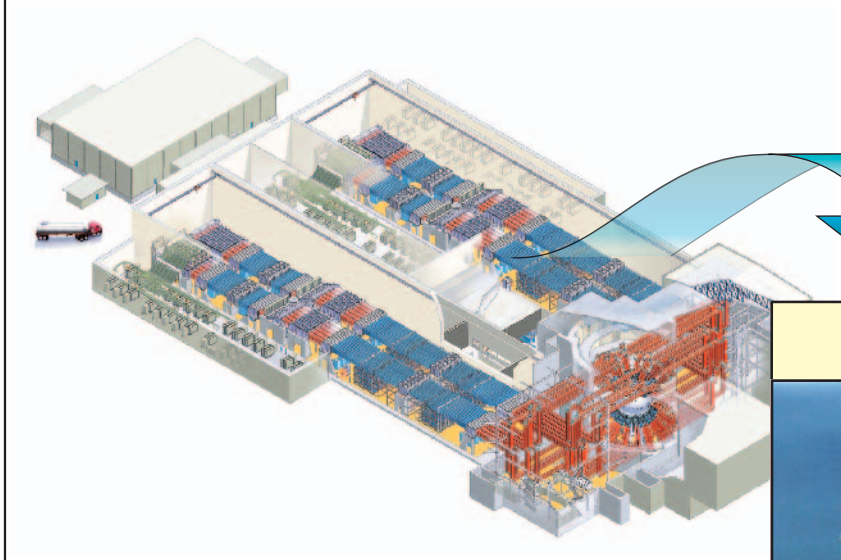
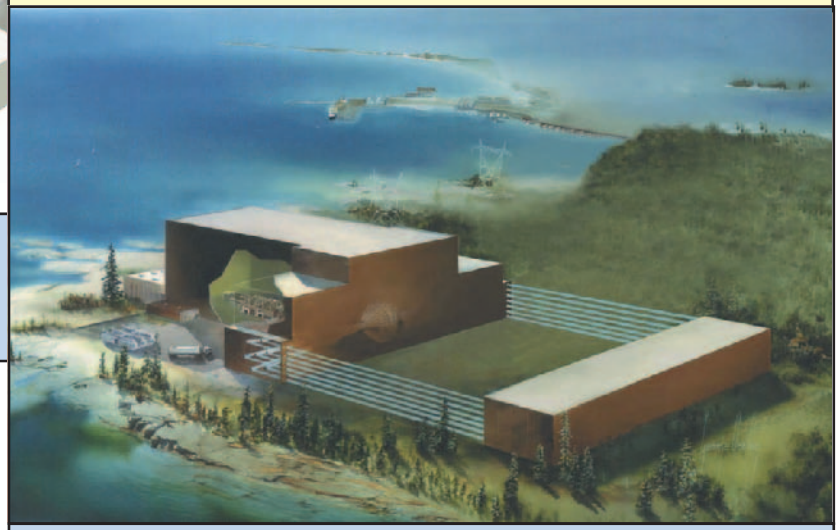
NIF



Repetition frequency 10^{-4} Hz
Electrical efficiency 0.5%

Fusion Reactor



Repetition frequency 10 Hz
Electrical efficiency 10%

NIF is about 5 orders of magnitude more energetic than its earliest predecessor

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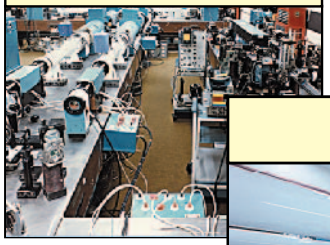
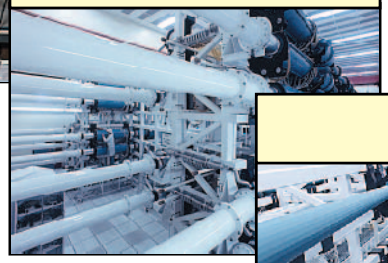
Janus 100J IR



Shiva 10KJ IR



Nova 30KJ UV

NIF 1.8MJ UV

Remaining Challenge:

- Rep rate
- Efficiency

The Mercury Laser is the first step toward building a MW, 10 Hz class of IFE lasers

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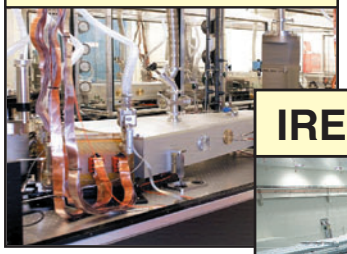
Mercury

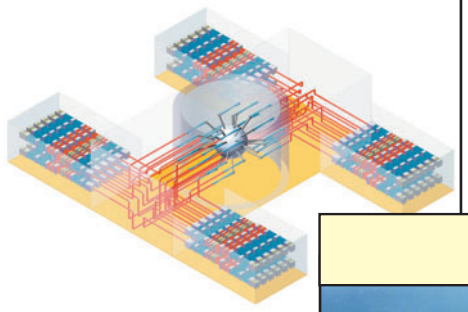


100 J IR

IRE (NIF bundle)

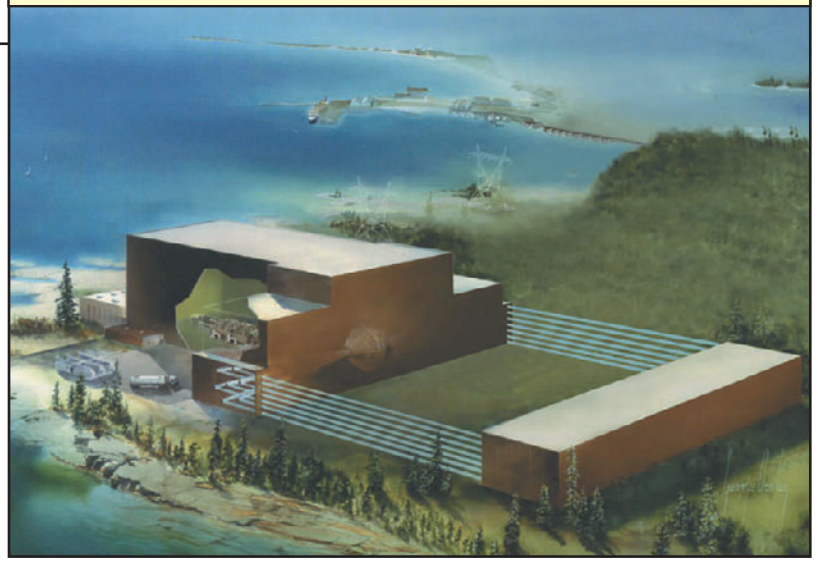
20 kJ UV

ETF



2 MJ UV

IFE



Mercury Goals:

- Energy: 100 J
- Efficiency: 10%
- Repetition rate: 10 Hz
- Pulse length: 3-10 ns
- Wavelength: 0.53/0.25 μm
- Bandwidth: 150 GHz 1ω
- Beam quality: 5 xDL

Mercury Laser at LLNL

NIF-0305-10505
18CB/cls

P8587

Future IFE solid state laser

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- Technical laser requirements
  - Energy/power to drive target
  - Beam conditioning
  - Efficiency optical-optical efficiency > 0.2
  - ASE $\alpha \cdot \ell < 4.5$
  - Beam filamentation $\delta B < 1.8$
- IFE specific constraints
  - Cost
  - Rep rate
  - RAM

safe, efficient and reliable

- Near term challenges:
  - Choice and size of gain medium
  - Reduction of diode costs

Projected diode costs support economic IFE driver

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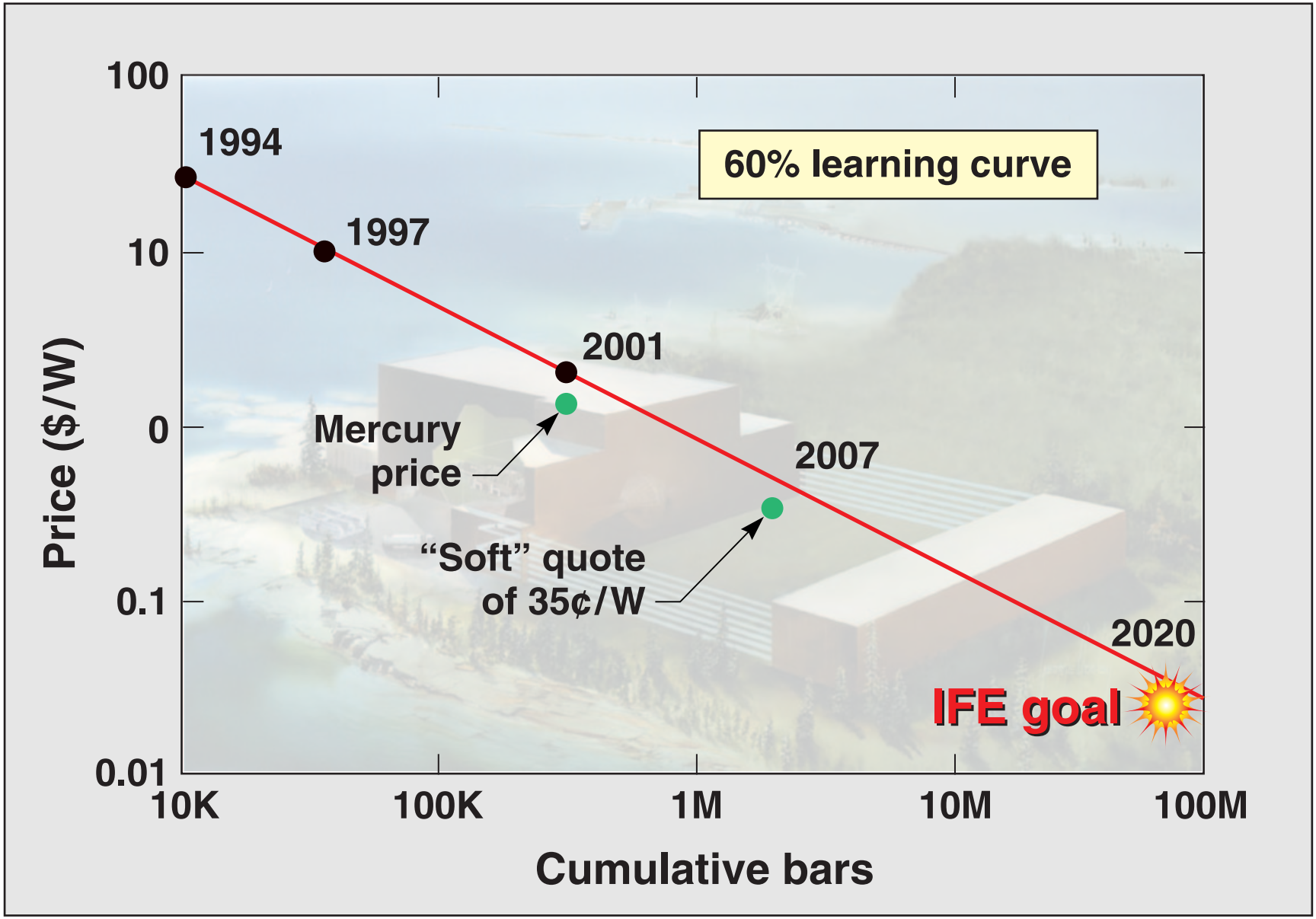

Innovations in new gain materials open up architectural options

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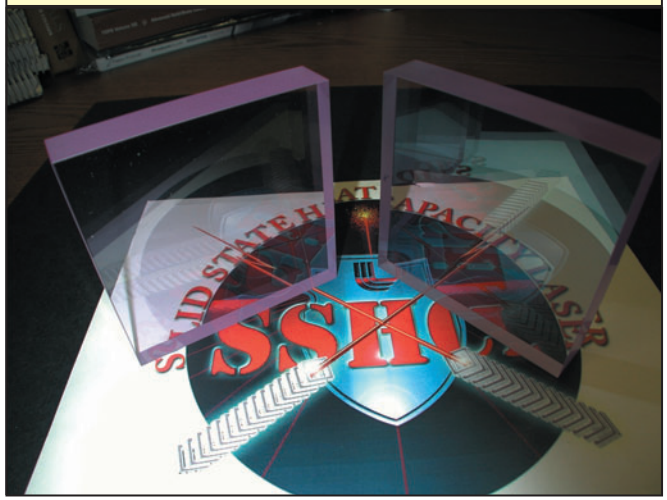
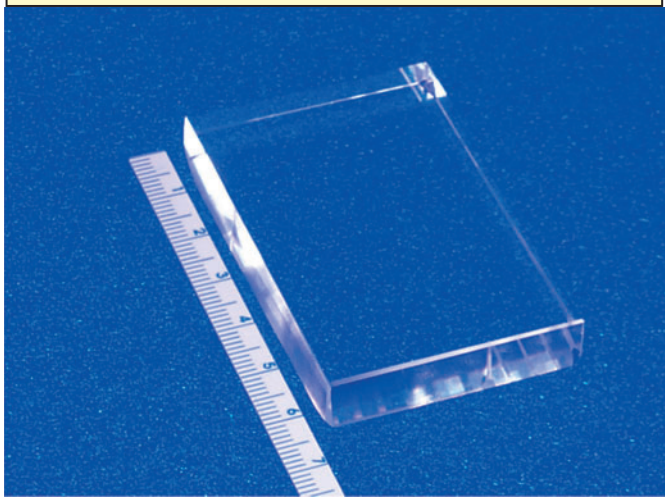
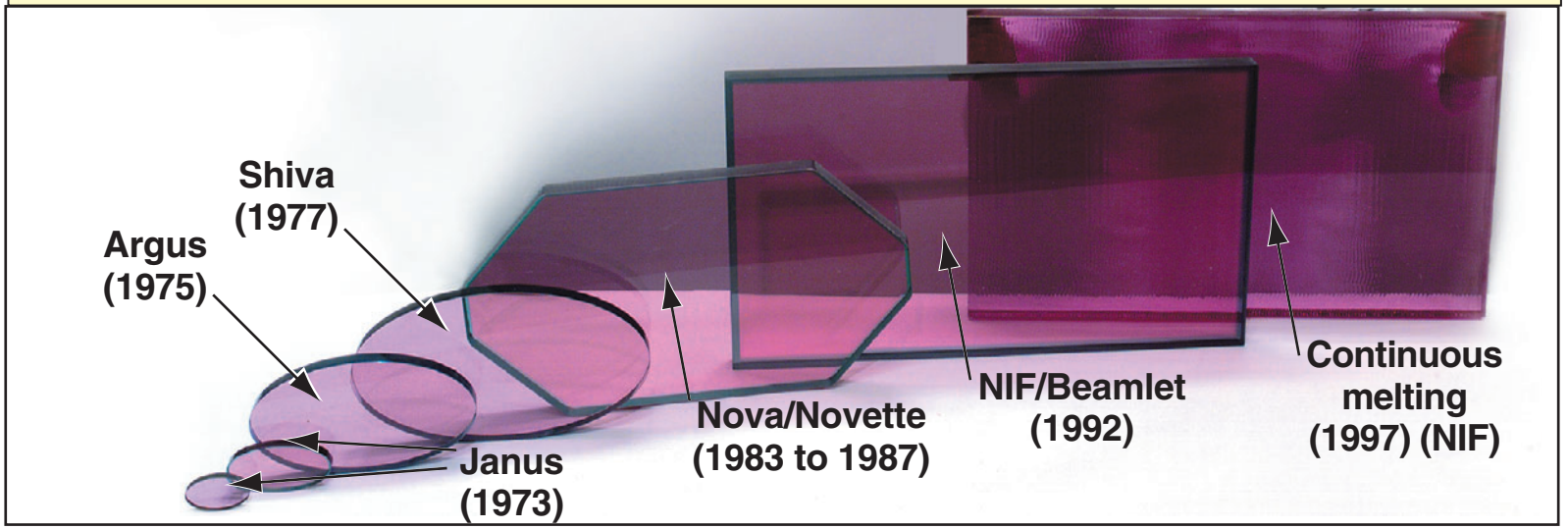
Ceramic Nd:YAG



Czochralski Yb:S-FAP



Continuous Melt Nd:Glass



Facility comparison

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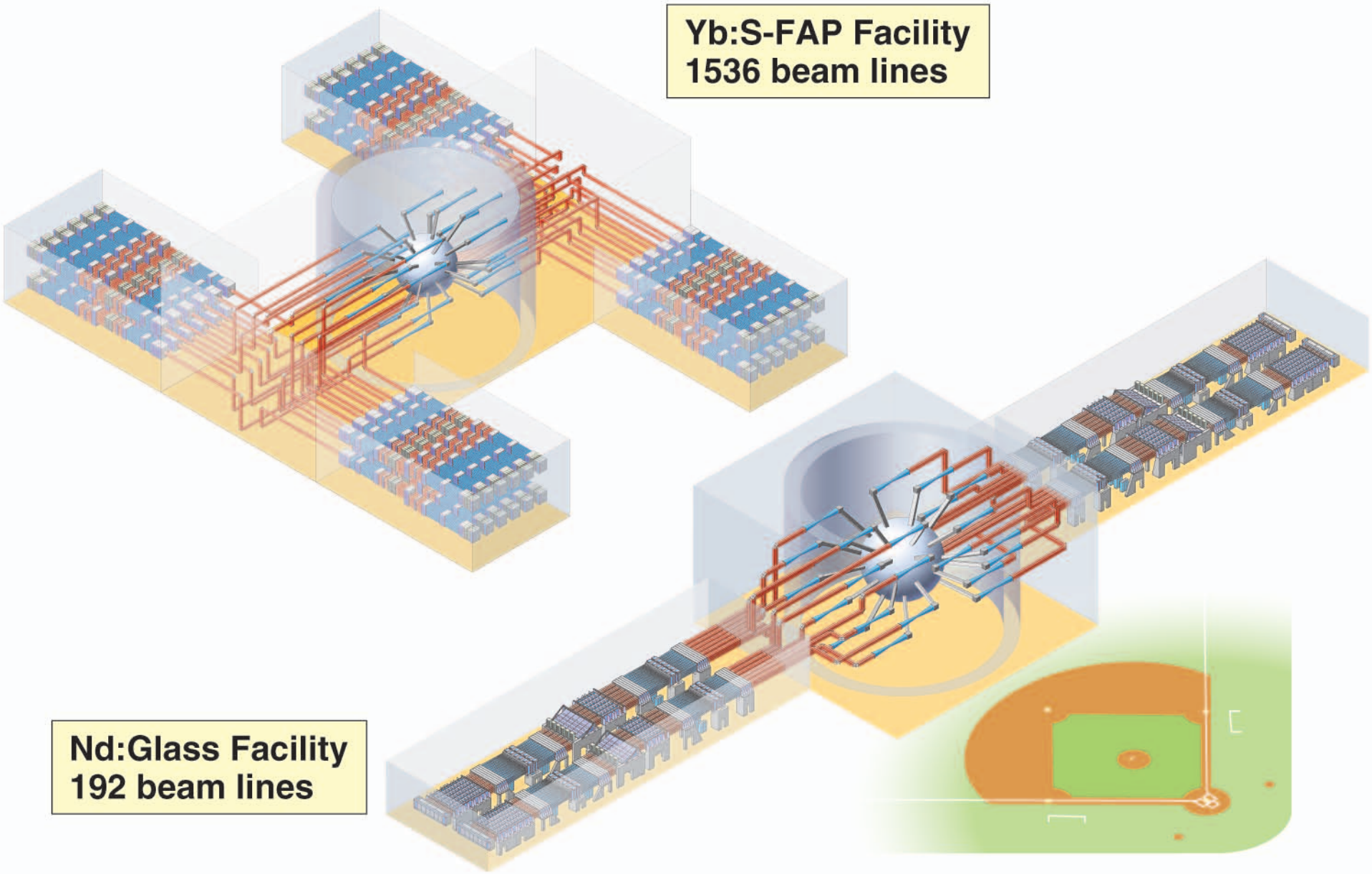

Leveraging the NIF provides a near-term pathway to the demonstration of an IRE beam line

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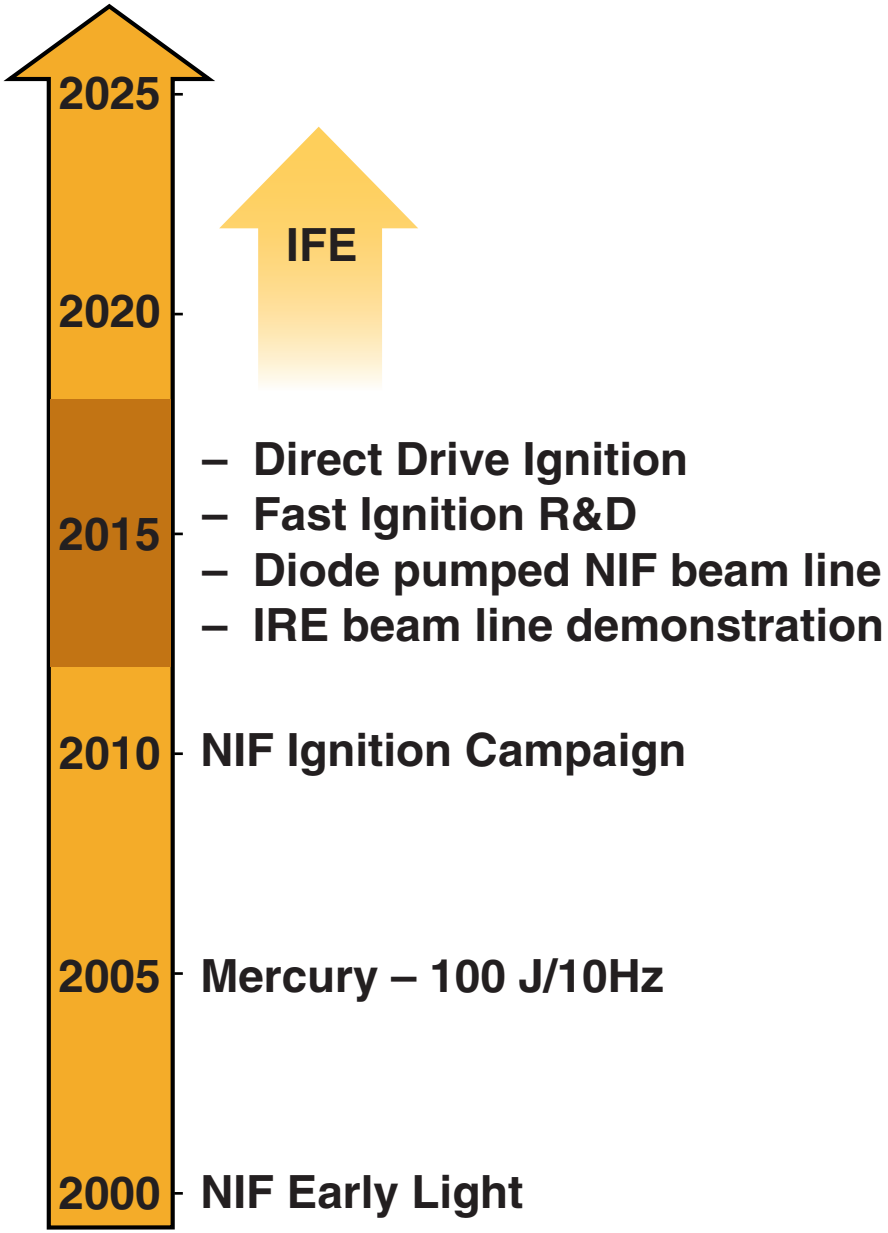

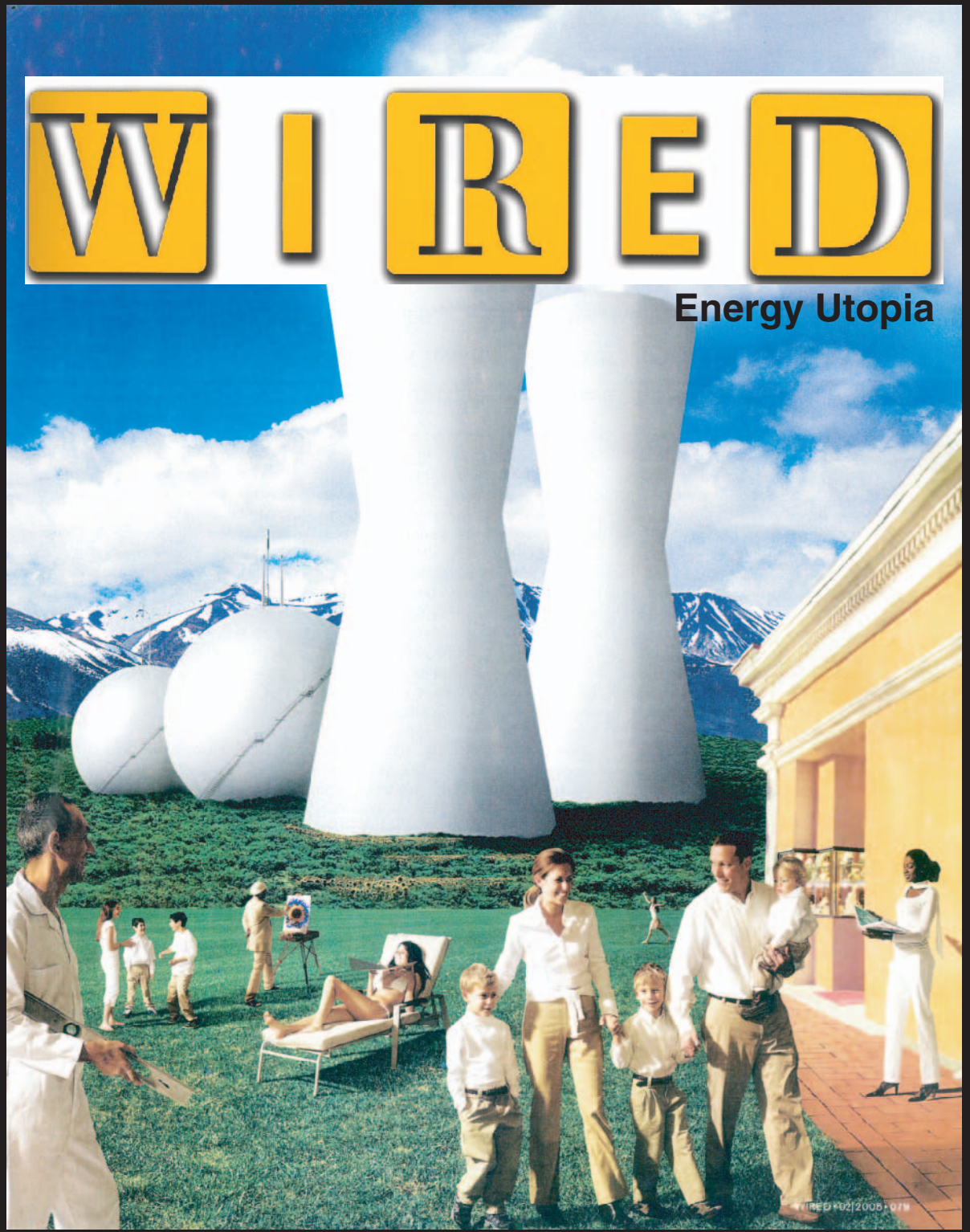

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