LLNL-PRES-581132

LIFE

Progress towards a Compact Laser Driver for Laser Inertial Fusion Energy

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Lawrence Livermore National Laboratory

High Energy Class Diode Pumped Solid State Lasers Workshop

September 12, 2012

Granlibakken Conference Center, Lake Tahoe, CA

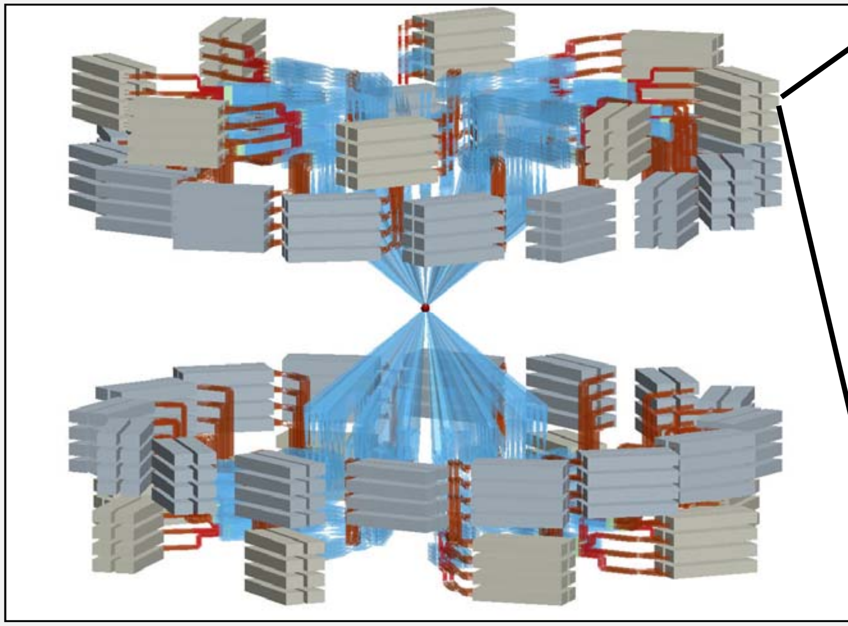
This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344

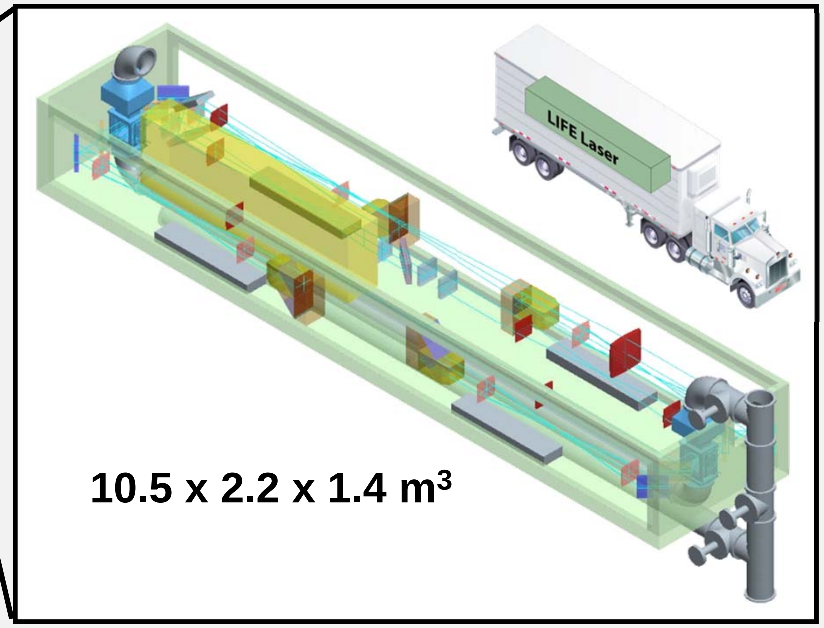
The National Ignition Facility

LIFE is a modular laser system which allows realistic reliability specifications, affecting plant availability by <1%

1ω “Beamline in a box” fits in a semi trailer

A >100m NIF beamline is compressed into a <11m box





Modular, truck-shippable, swappable beamlines enable
- **practical power plant supply chain**
- **high availability laser**

NIF capability in a very small box:
LIFE high average power laser architecture attributes

Provides efficiency (~18%) at high repetition rate (16 Hz)
- High brightness efficiency diode pump arrays
- Helium gas-cooled amplifiers
- High efficiency harmonic conversion using pulse splitting

Will be built with existing materials
- Glass slabs: thermal birefringence compensated by architecture
- DKDP Pockels cell: polarization switching minimizes heat load

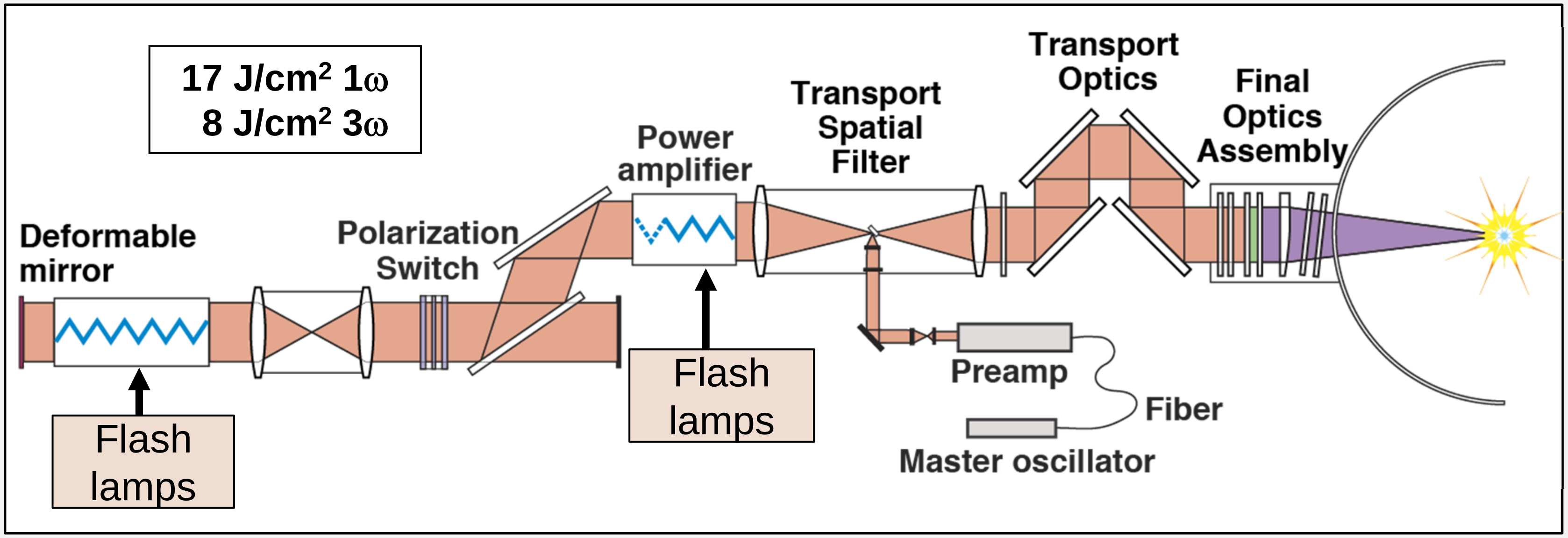
Designed for high availability operation
- Robustness: Low 3ω fluence operation
- Headroom in beamline power to meet operational availability
- Optics preparation to mitigate damage

Suitable for remote (off-site) manufacturing
- Modular beamlines permit hot-swapping
- Separation of laser manufacturing & power generation operations

Laser Bay

The NIF laser provides the single-shot baseline

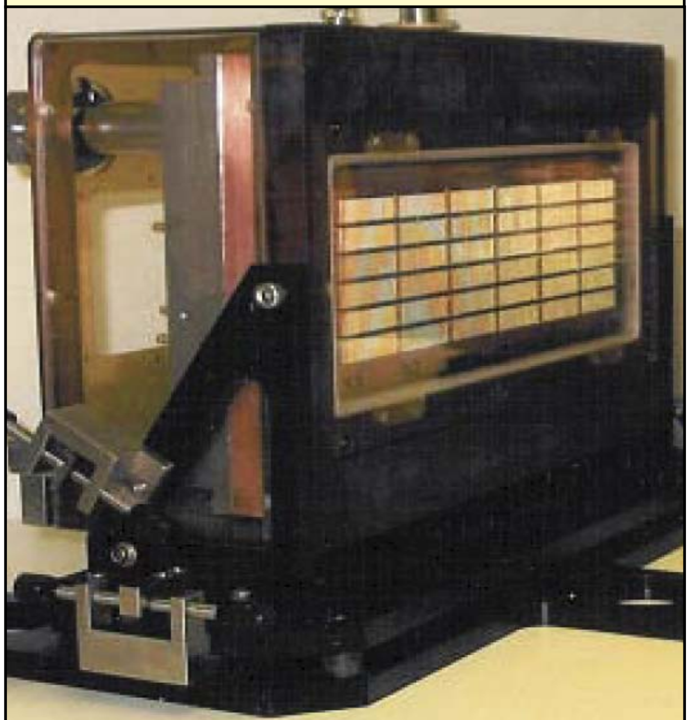
NIF Beamline



- Master oscillator / Preamplifier / Multi-pass architecture
- Passive optical system performance
- Line Replaceable Unit (LRU) methodology
- Whole-system design, construction, commissioning and operation
- Optics production and performance experience base
- Coupling demonstration to full-scale IFE target

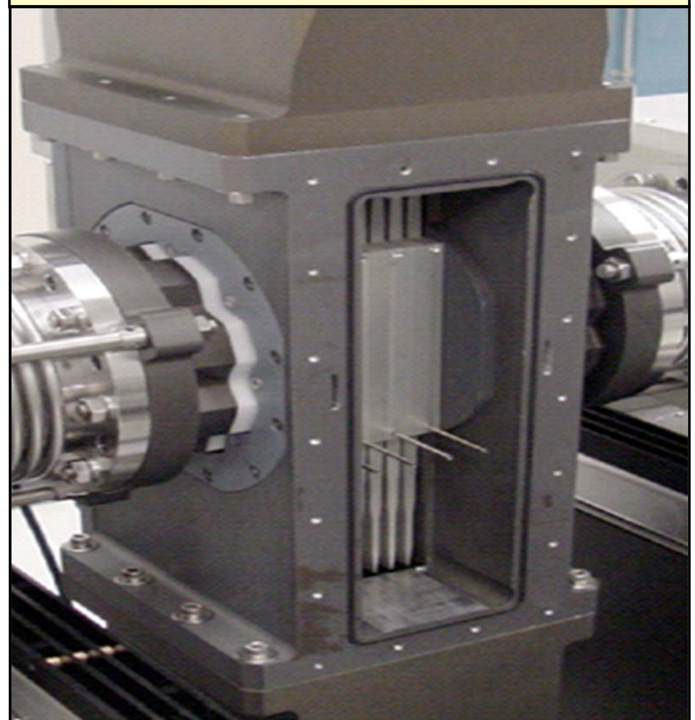
Laser diodes and helium gas cooling enable a NIF-like architecture to meet LIFE driver requirements

High Power Diode Arrays



100 kW peak power

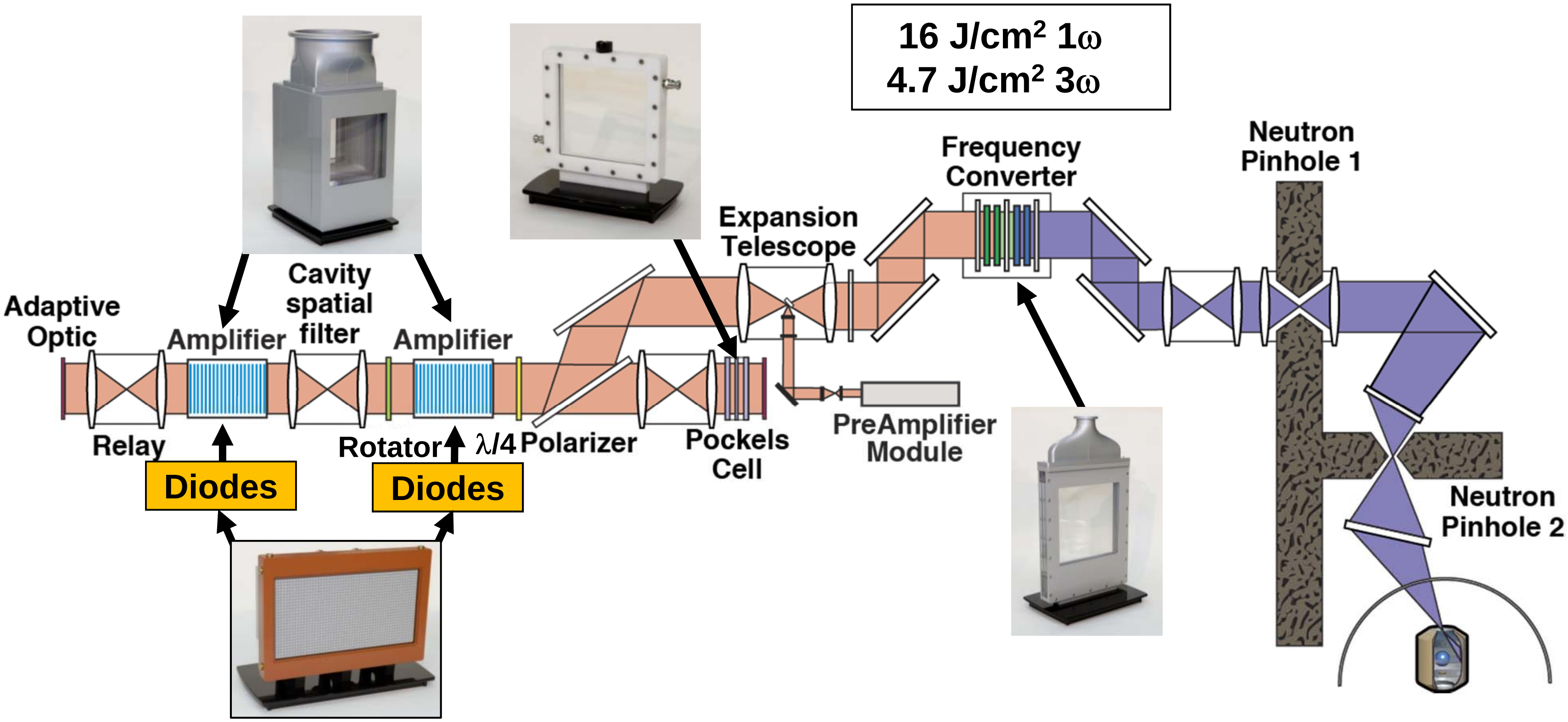
High Speed Gas Cooling



3 W/cm^2 cooling (average)

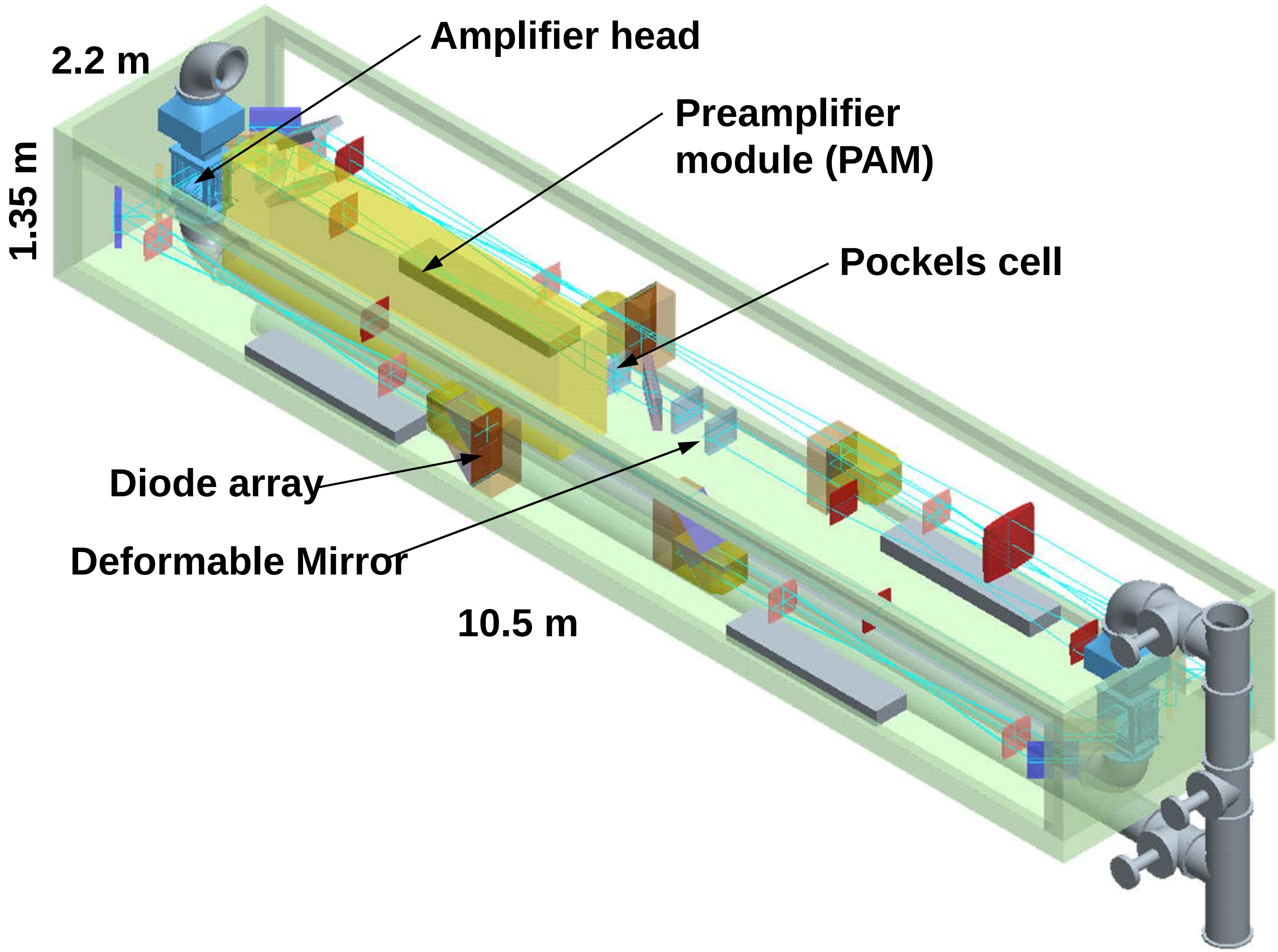
These technologies have been developed as part of the Mercury HAPL Project

LIFE combines the NIF architecture with high efficiency, high average power technology



Diode pumps	→	high efficiency (18%)
Helium cooled amps	→	high repetition rate (16 Hz) with low stress
Normal amp slabs	→	compensated thermal birefringence, compact amp
Passive switching	→	performs at repetition rate
Lower output fluence	→	less susceptible to optical damage

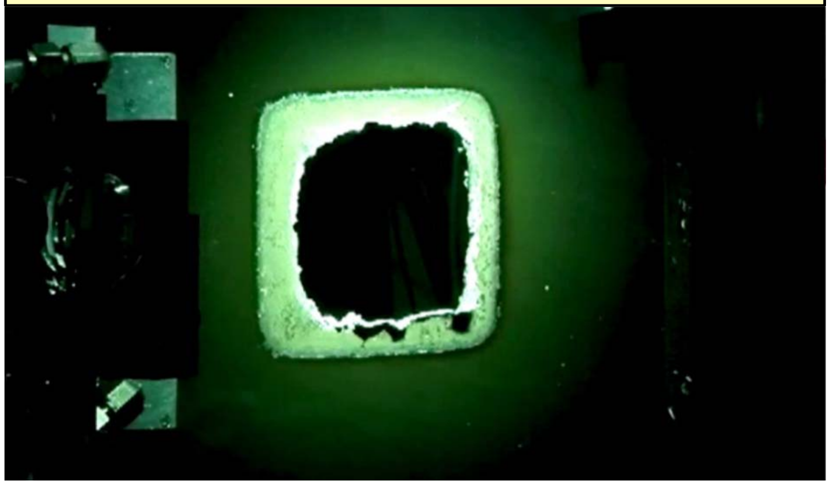
The entire 1ω beamline can be packaged into a box which is 31 m^3 while providing 130 kW average power



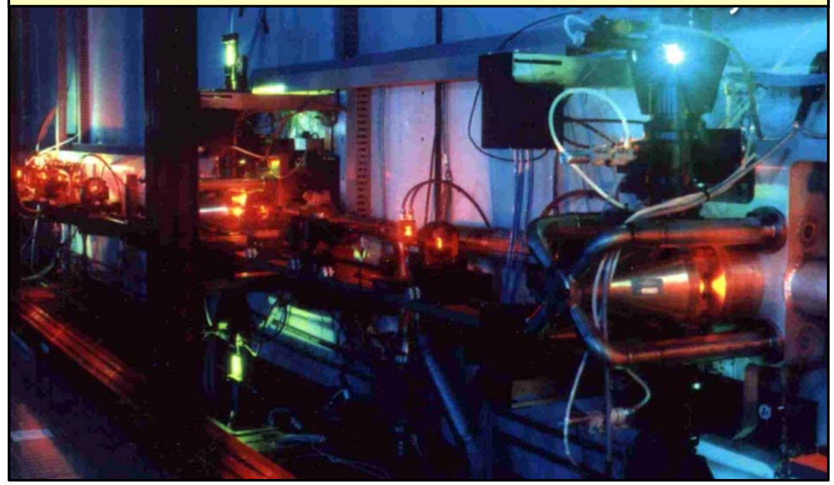
LIFE Box in NIF Laser Bay

LLNL average power lasers have been proving grounds for several key LIFE technologies

25 kW high average power laser



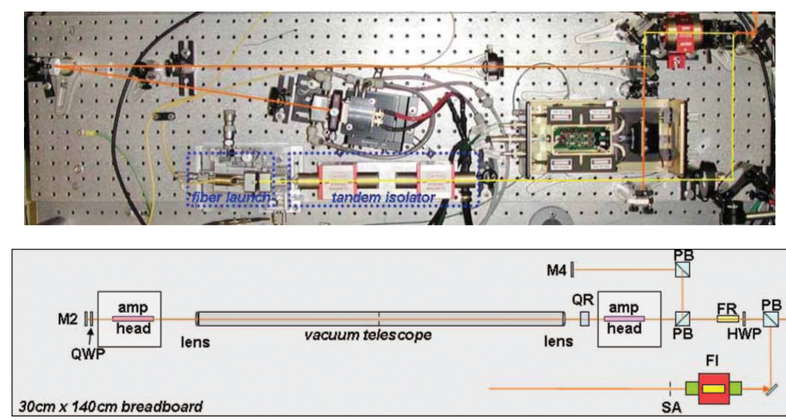
AVLIS 24/7 operational laser



600W, 10 Hz Mercury Laser

A.J. Bayramian et. al, *Fusion Sci. Tech.* 52, 383 (2007)

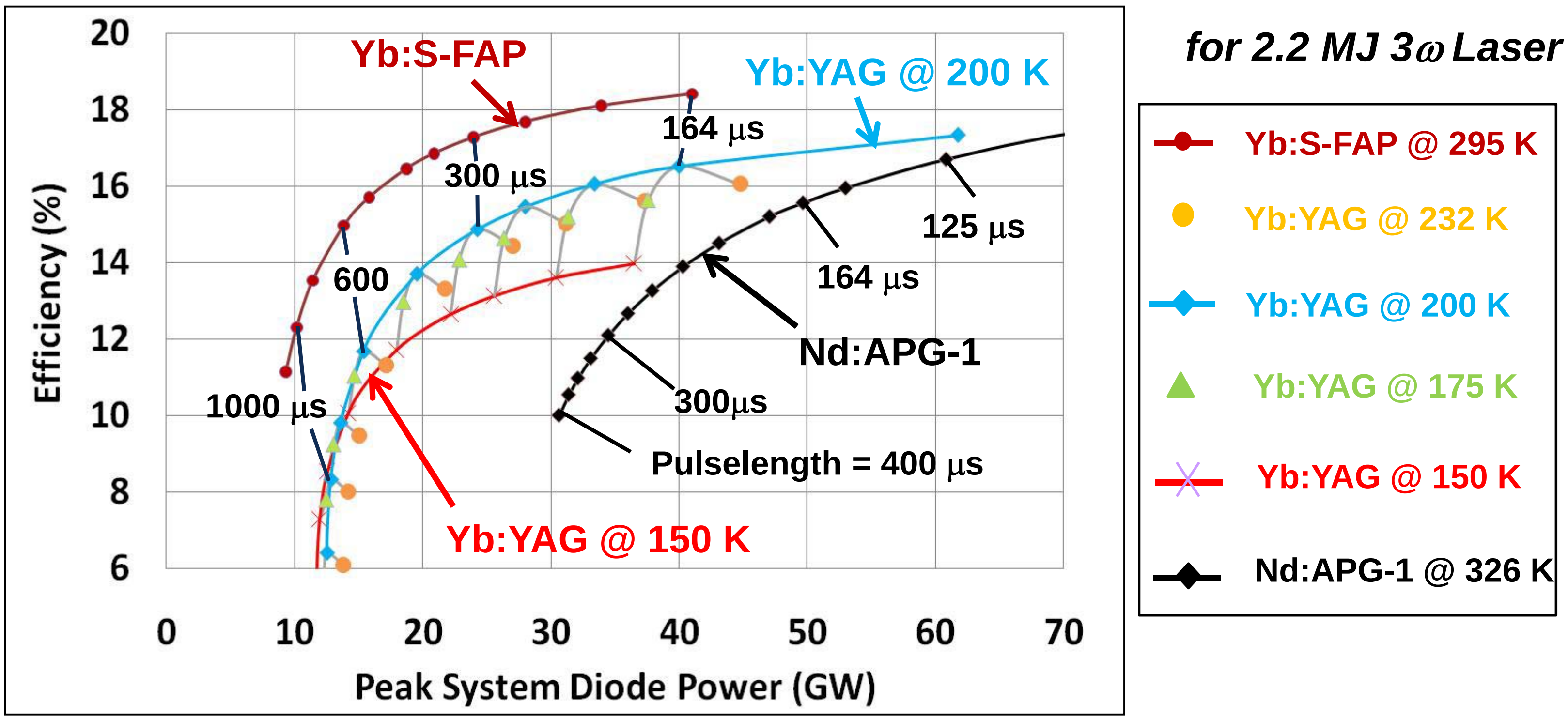
300 Hz, 38 W Pulse Amplifier



J. Honig, et. al, *Appl. Opt.* 46, 3269 (2007)

Efficiency-cost tradeoffs: Nd vs. Yb gain media

Efficiency vs. Pump Power vs. Cooling Architecture

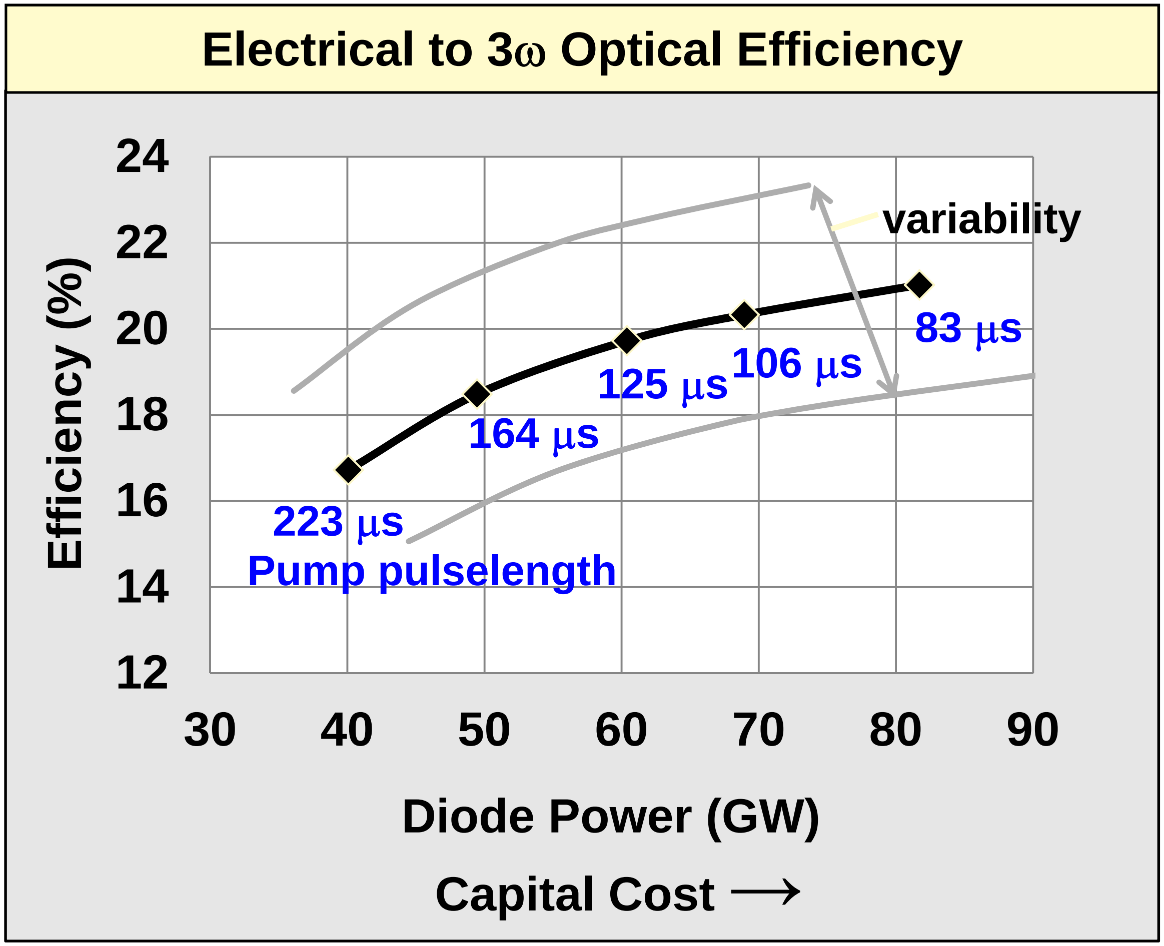


Erlandson, et al., Invited Paper, Opt. Mat. Express, 2011; *Patent filed: IL-12308*

Our results

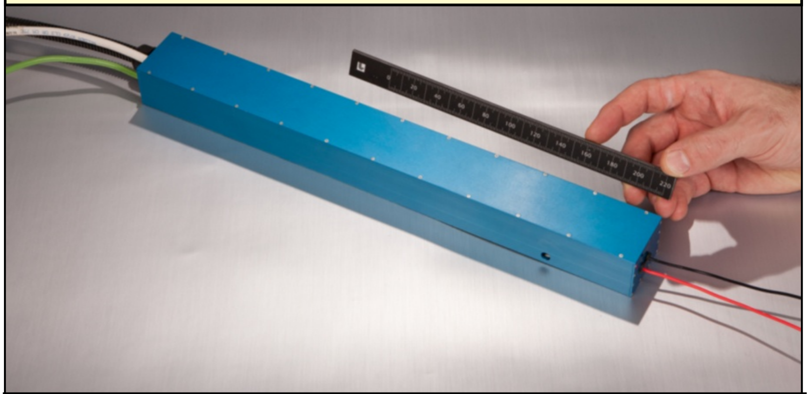
- quantify the benefits of advanced materials
- show that cooling architecture is critical to capitalize on Yb:YAG

The LIFE laser will achieve high efficiency, optimized at ~18% to balance economic and performance terms



Diode power conditioning has been made practical for the footprint and efficiency needed for Beam-in-a-Box

Single pulser unit of Diode Power Conditioning for LIFE

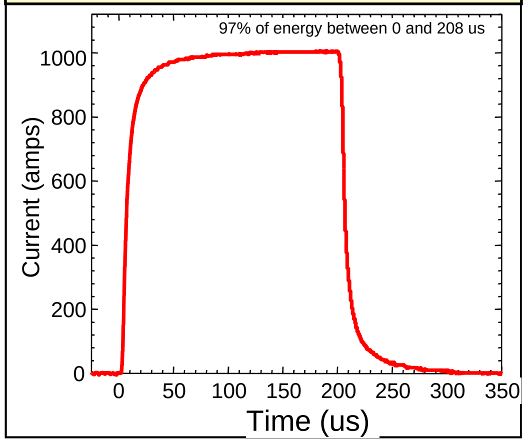


Size: 3.66 x 4.76 x 40.96 cm^3

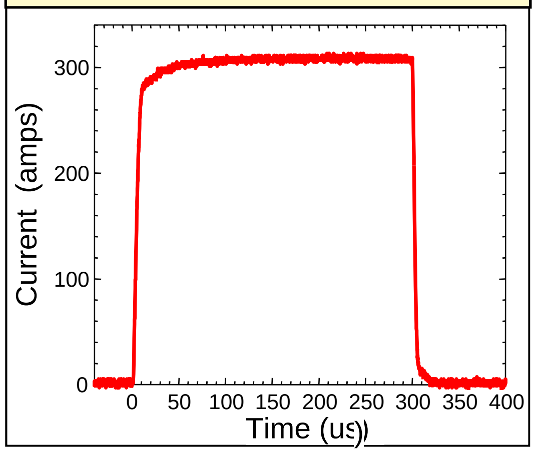
- **Smart Pulser**
  - — **"A more compact and efficient diode pulser"**
  - — **High average power (12.5 kW)**
  - — **High current (1000A)**
  - — **High efficiency (90%) (95% efficiency possible with double size pulser**
  - — **Low volume diode pulser (713 cm3)**
  - — **Benefit: 10X average power, 10X decreased volume**
- **Licensing**
  - — **This technology is currently being developed by a commercial company**

These pulsers are now being used in the lab for diode laser testing

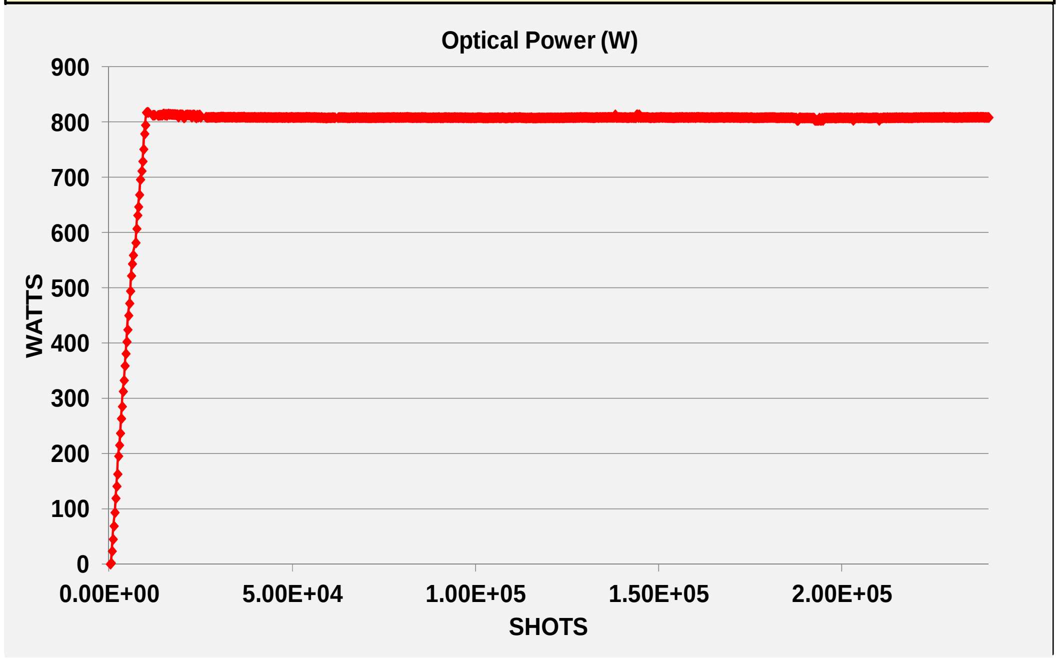
1000A dummy load



10-bar diode stack



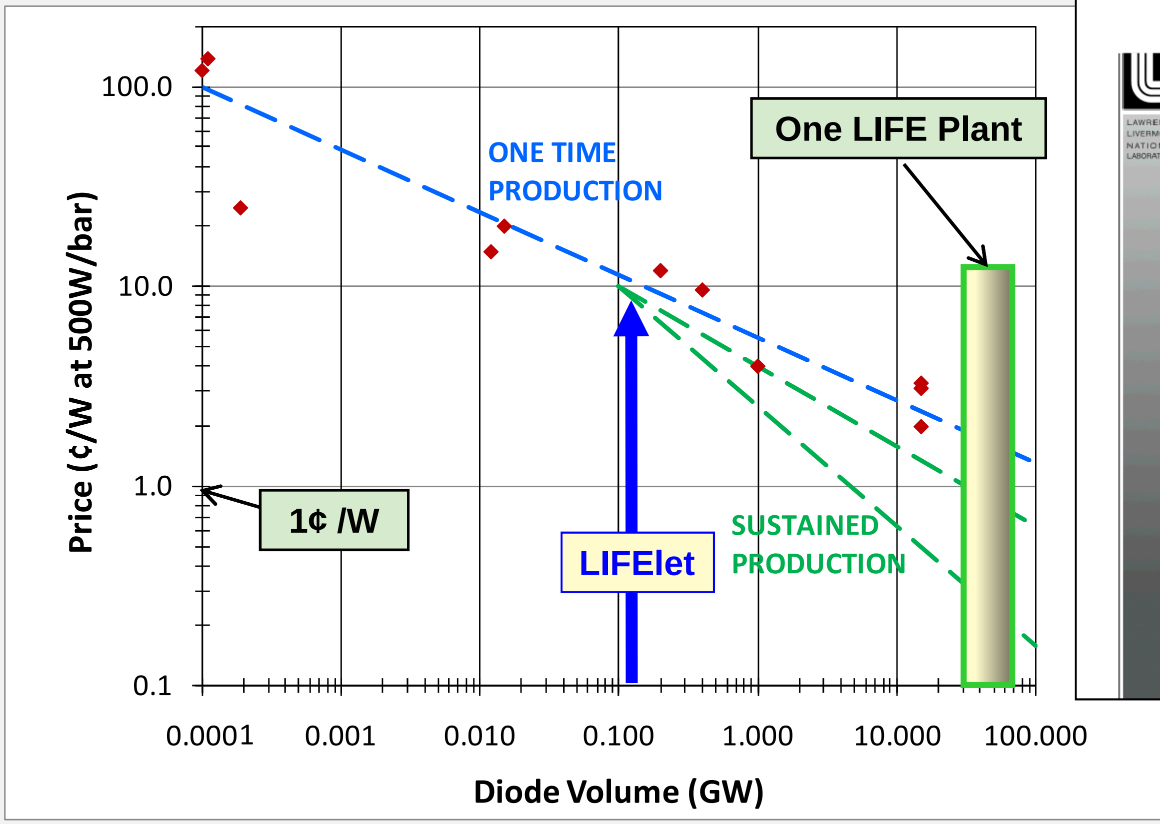
Early Lifetime testing

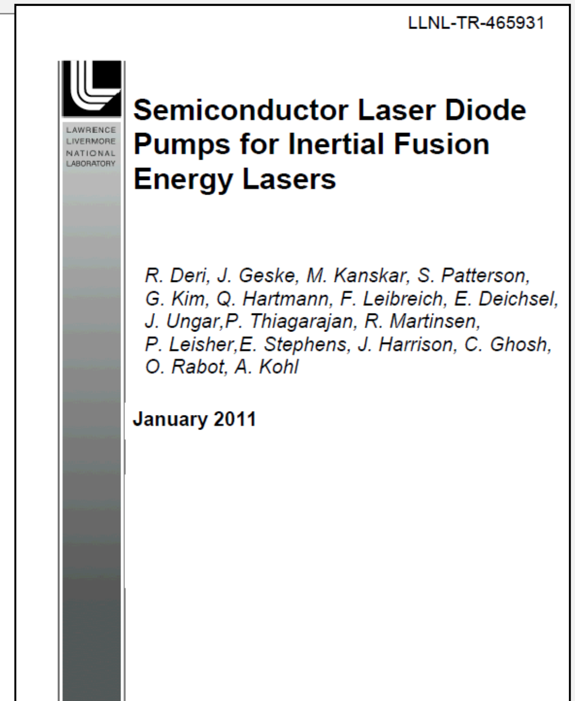


- **Once characterized, these early bar analogs similar to those needed for LIFE will undergo Mshot to Gshot lifetests**
- **Mshot testing underway now**

Diode technology will meet Beam-in-a-Box cost targets

- White paper co-authored by 14 key laser diode vendors
- 2009 Industry Consensus: 3¢/W @ 500 W/bar, with no new R&D





LLNL-TR-465931

Semiconductor Laser Diode Pumps for Inertial Fusion Energy Lasers

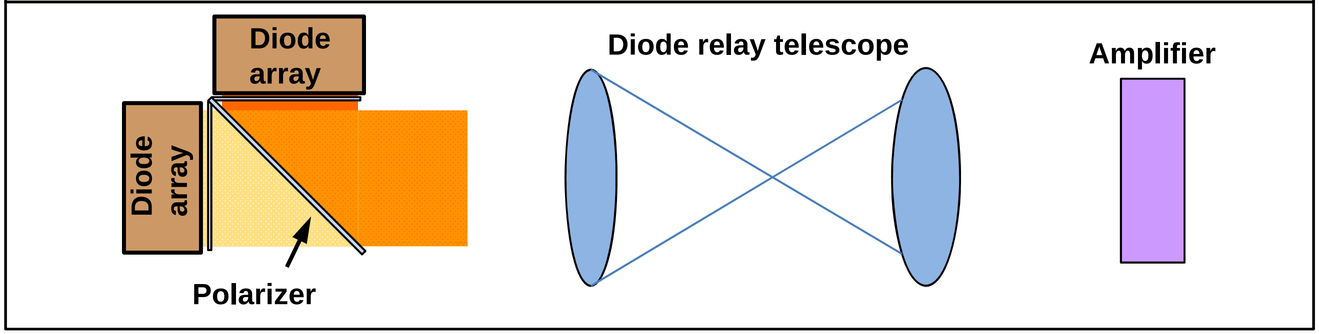
R. Deri, J. Geske, M. Kanskar, S. Patterson, G. Kim, Q. Hartmann, F. Leibreich, E. Deichsel, J. Ungar,P. Thiagarajan, R. Martinsen, P. Leisher,E. Stephens, J. Harrison, C. Ghosh, O. Rabot, A. Kohl

January 2011

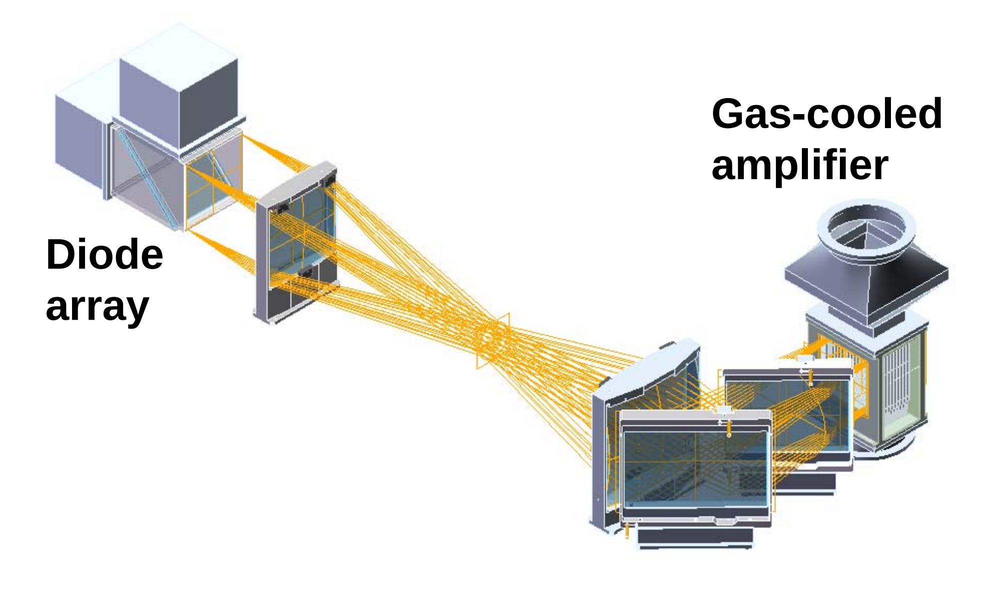
- Power scaling to 850 W/bar provides $0.0176/W (1st plant)
- Sustained production of LIFE plants reduces price to ~$0.007/W
- Diode costs for first plant: $880M
- Diode costs for sustained production: $350M

Each beam box includes ~130 MW of polarization combined diode pumps

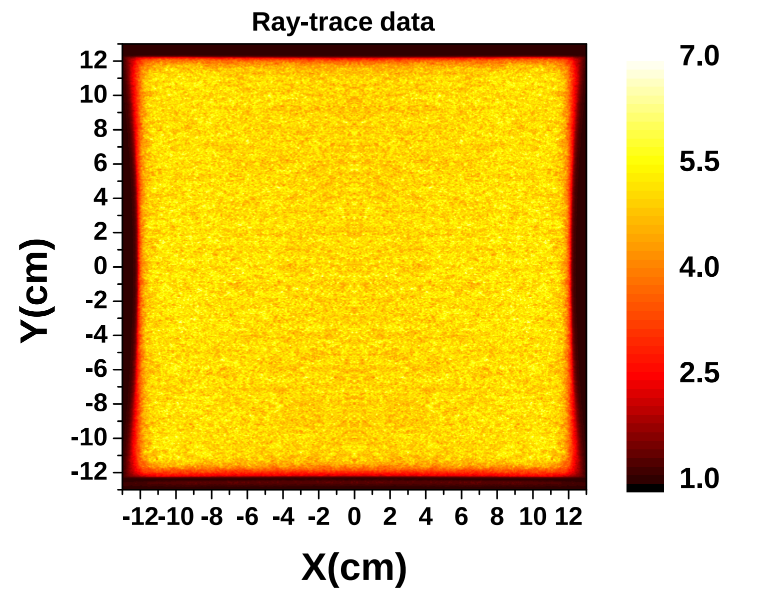
Schematic of pump delivery method



Solid model of the LIFE amplifier system

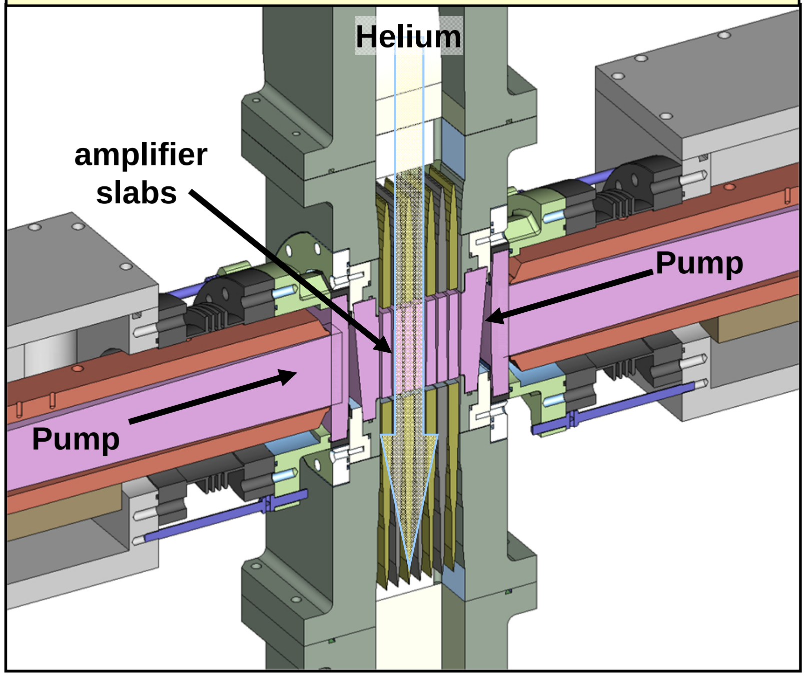


Amplifier Diode Pump Profile (Gain)



Amplifier heads employ gas-cooled glass slabs to remove heat longitudinally mitigating thermal lensing

Gas Cooled Amplifier Head



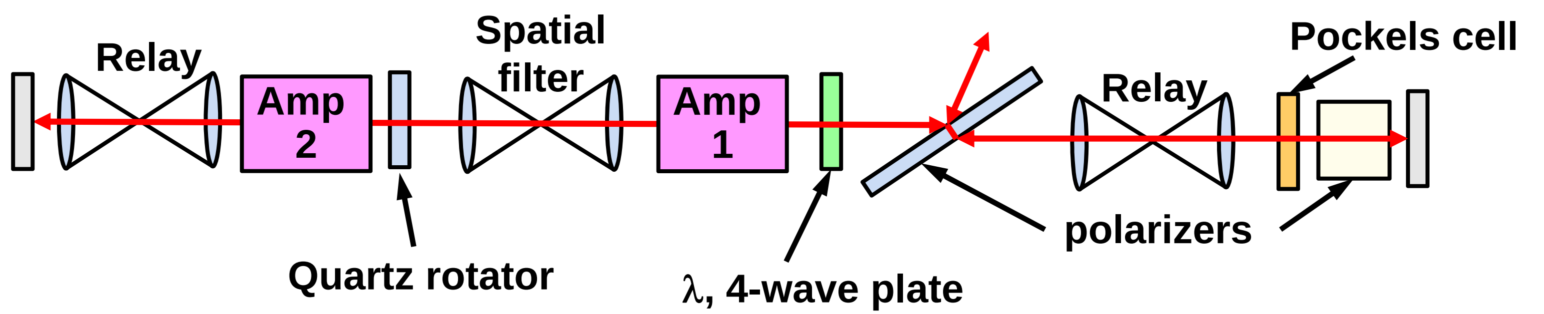
Details

- **20 glass slabs**
- **Aerodynamic vanes**
- **5 atm Helium**
- **Flow rate Mach 0.1**

This amplifier design was prototyped and thermal / gas cooling codes benchmarked on the Mercury laser system

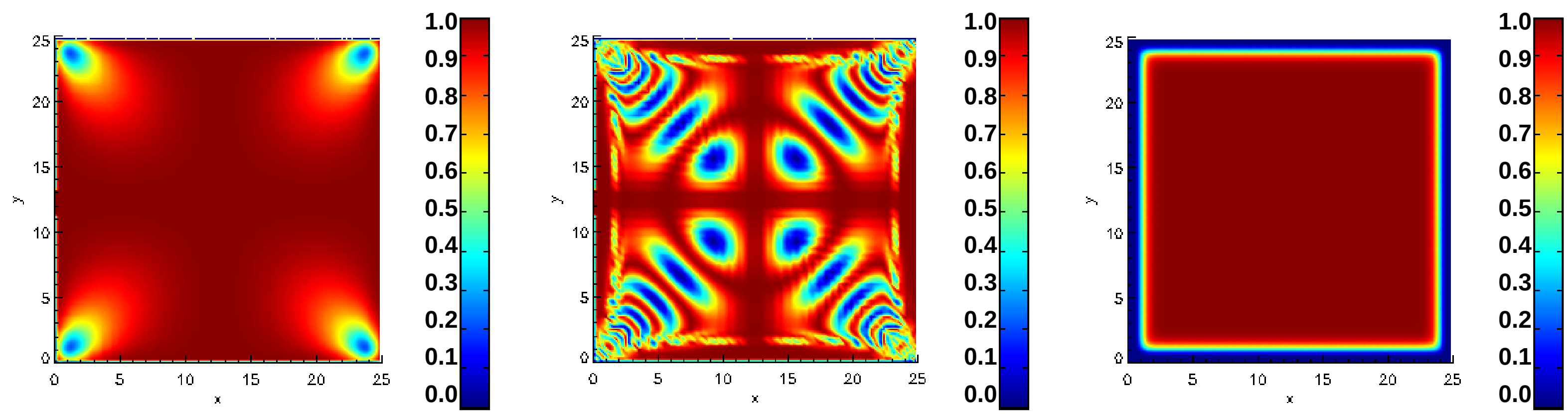
Thermally induced depolarization in isotropic media (Nd:glass) can be minimized with polarization rotation

Architecture



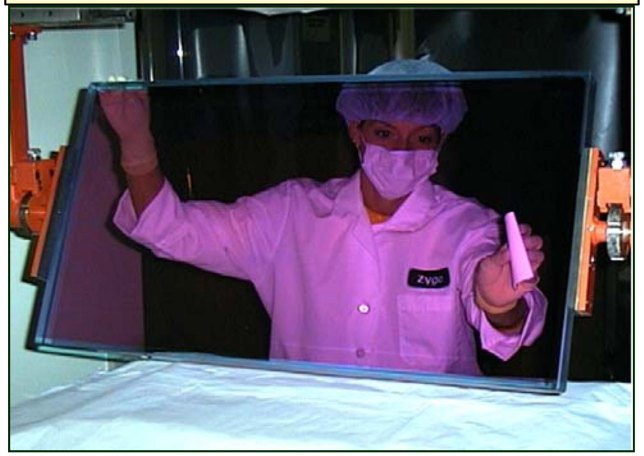
Polarized transmission of amplifier components

1 slab	1 amplifier (20 slabs)	2 amplifiers (compensated)



The materials chosen for the LIFE laser are based on today's availability to meet schedule

Nd^{3+}: phosphate laser glass



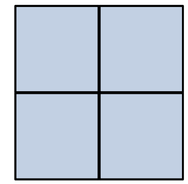
HEM Sapphire & EFG Sapphire waveplates

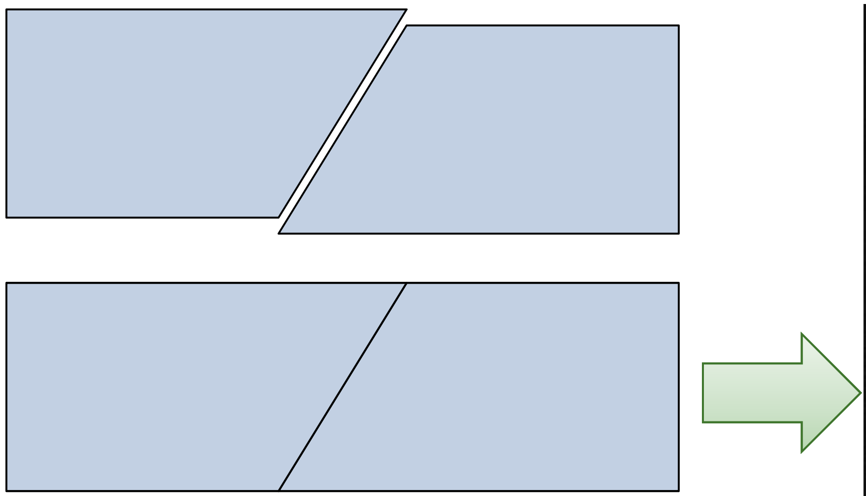
Quartz crystal rotators

KDP and DKDP frequency conversion crystals

LIFE requires a 25 x 25 cm^2 aperture quartz rotator, however, quartz is not yet available in this size

- **Quartz crystals can produce a 15 x 15 cm aperture today (Sawyer Corporation)**
- **Bonding of 4 parts together will yield a full size optic.**
- **We are doing our first test bonds in collaboration with Precision Photonics Corporation**
- **Polished parts bonded with CADB (Chemically Activated Direct Bonding)**



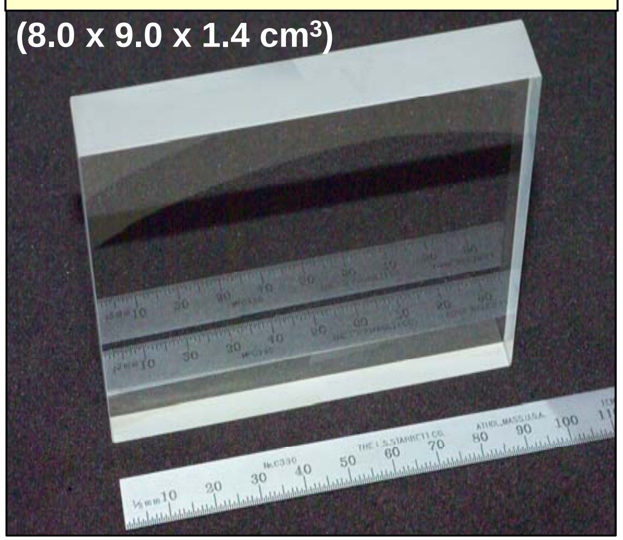


Validation experiments on quartz rotator material indicate potential to meet LIFE beamline requirements

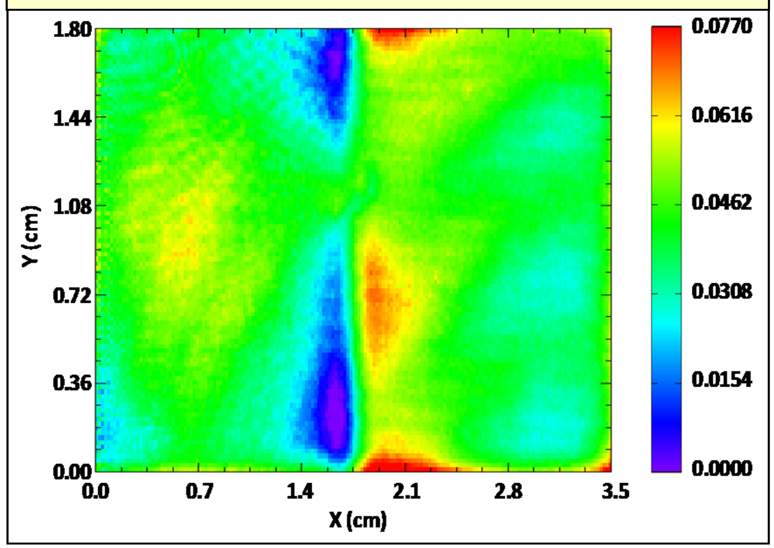
First characterization of a bonded quartz rotator shows promise

- **Transmitted wavefront (<lambda/14 without MRF correction) & rotation (>99.9%) are reasonable for this first demo**
- **Raster scan damage testing was carried out at SPICA Inc. on three different samples using a 1064 nm 3 ns Nd:YAG laser system.**
- **First initiation sights were observed at 16 J/cm^2, 16 J/cm^2 and 49 J/cm^2 respectively.**
- **An additional test for 10^5 shots was successfully carried out at 10 J/cm^2 (nominal LIFE operational point for the rotator).**

Bonded Quartz Rotator



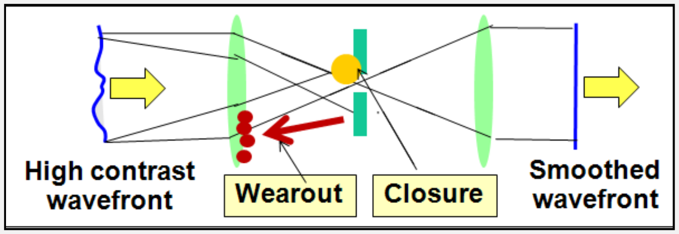
Transmitted wavefront error



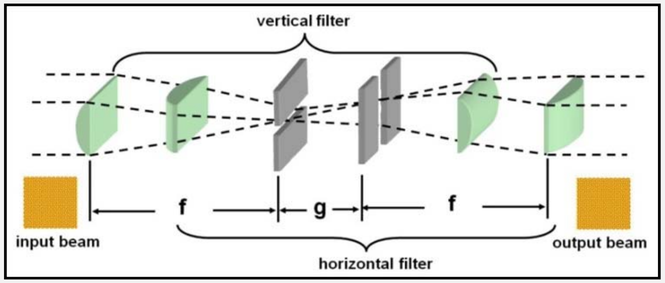
A cylindrical spatial filter can mitigate many issues associate with high average power / intensity

- Spatial filters are essential for high energy laser systems
  - Reset high frequency B-integral effects
  - Provide gain isolation
  - Improve laser beam quality
- High intensity in spatial filters is an issue
  - Exceeds pinhole melt / vaporization threshold
  - Pinholes degrade over time
  - Vaporized material can coat telescope optics

High Intensity Issues

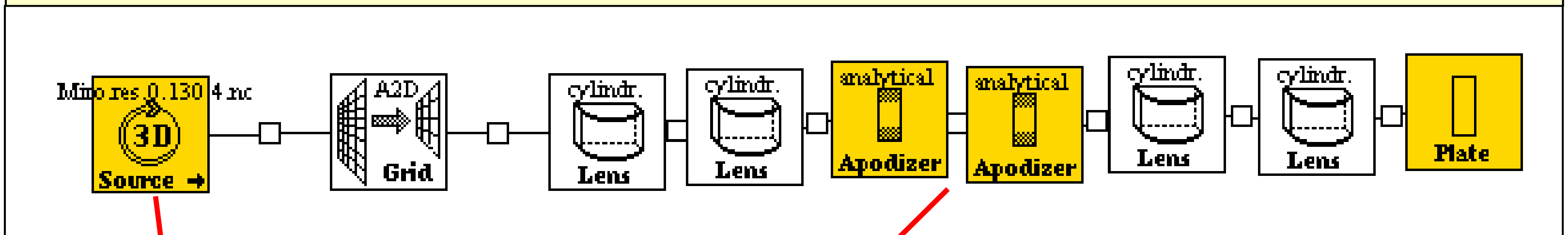


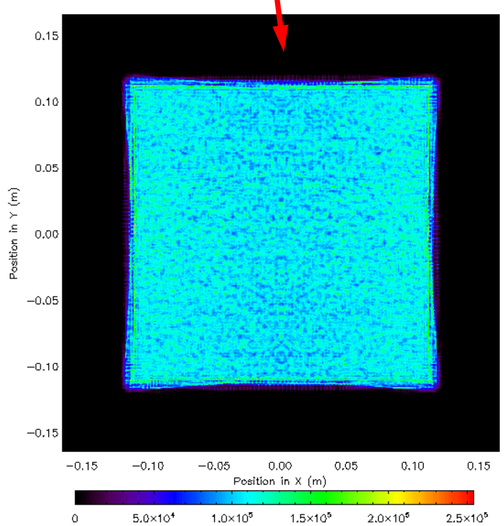
Cylindrical Filter Approach

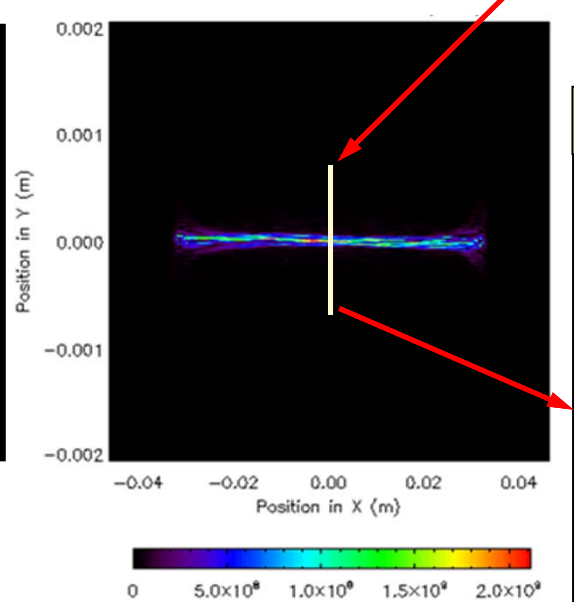


The calculated intensity profile on the cylindrical filter appears acceptable with real aberration files

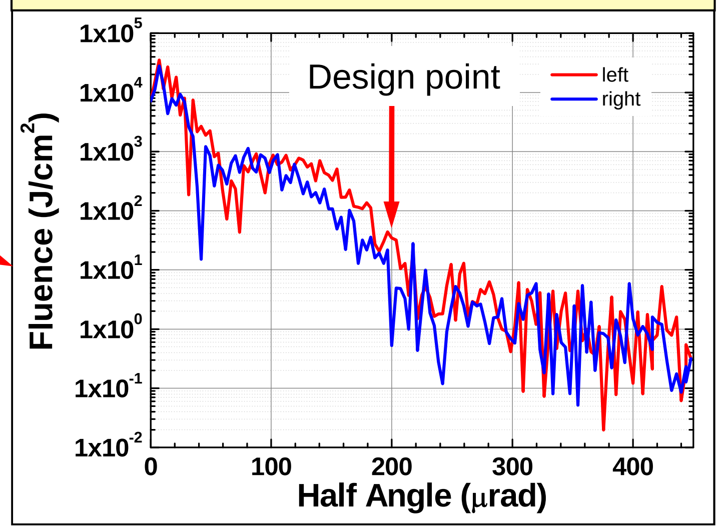
Complex field for final pass sent through Cylindrical Telescope in Miro







Fluence map on slit



Cylindrical filter experiments are proceeding well

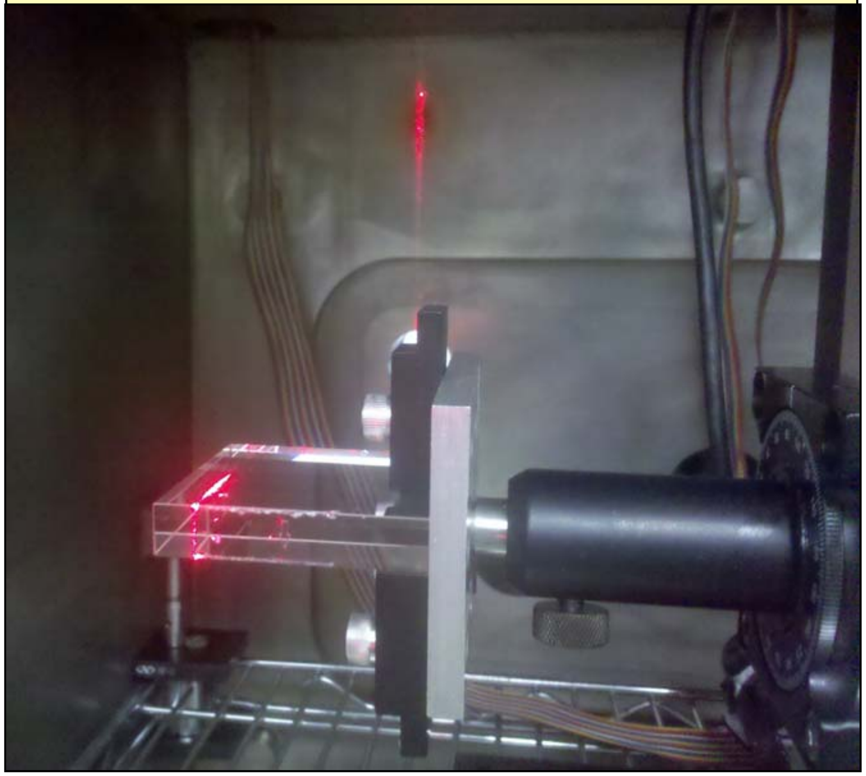
- **Slit filter substrates manufactured using NIF high damage threshold substrate, finishing, and cleaning procedures.**

Raster scan test results:

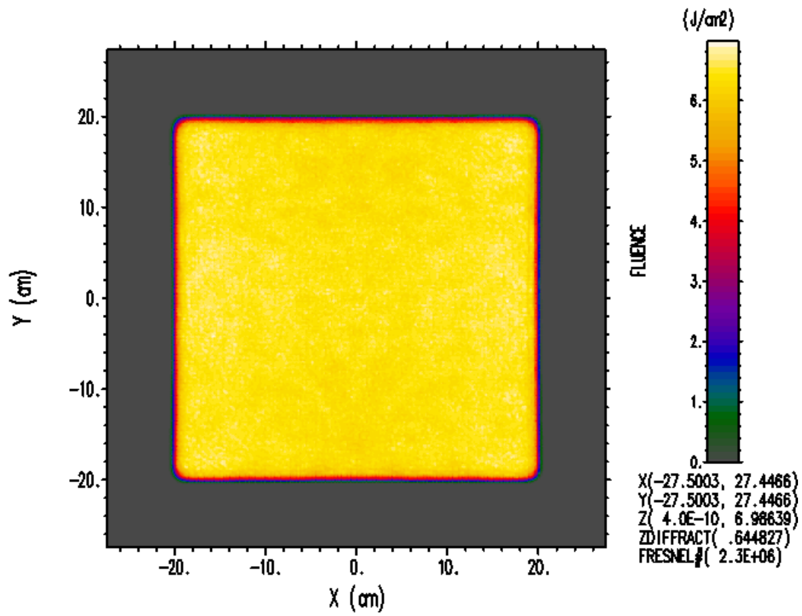
- **Successful ramp from 0 - 300 J/cm^2 in dry air (RH 5%)**
- **Successful ramp from 0 - 300 J/cm^2 in vacuum (mtorr)**
    - **Single damage spot at 150 J/cm^2 in vacuum – no other damage**

- **Lifetime testing underway to demonstrate 10^5 shots – so far 3.6x10^4 shots no damage**

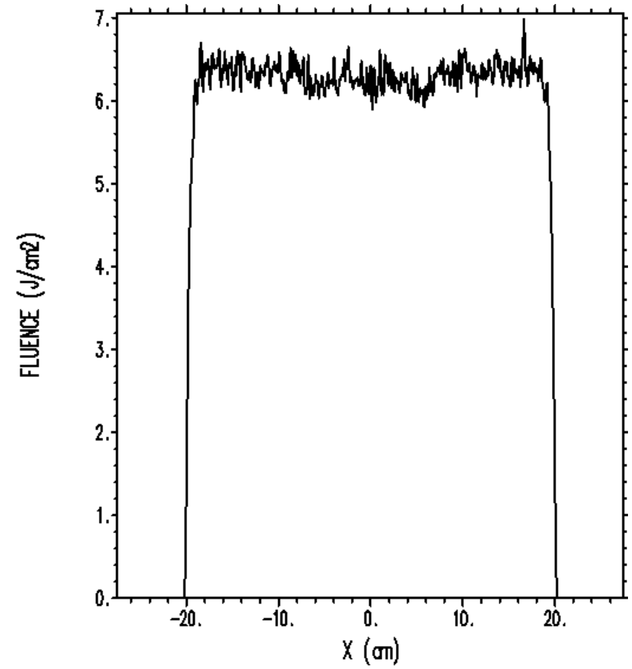
Testing apparatus at SPICA showing active test



PROP Model with New Optics Aberration Files: Results at Converter Input



High resolution 1024x1024 (500 micron pixels)

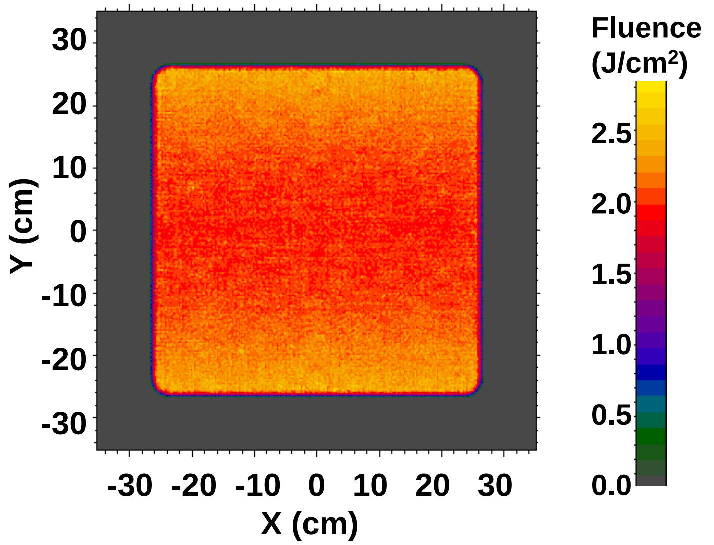


Mean 1ω fluence: 6.25 J/cm^2
Peak 1ω fluence: 6.99 J/cm^2
Contrast: 2.23%

- **More realistic aberrations using NIF optics database with no scaling**
- **Filtering of files to remove interferometer defects**
- **Wavefront improved slightly compared to original model**

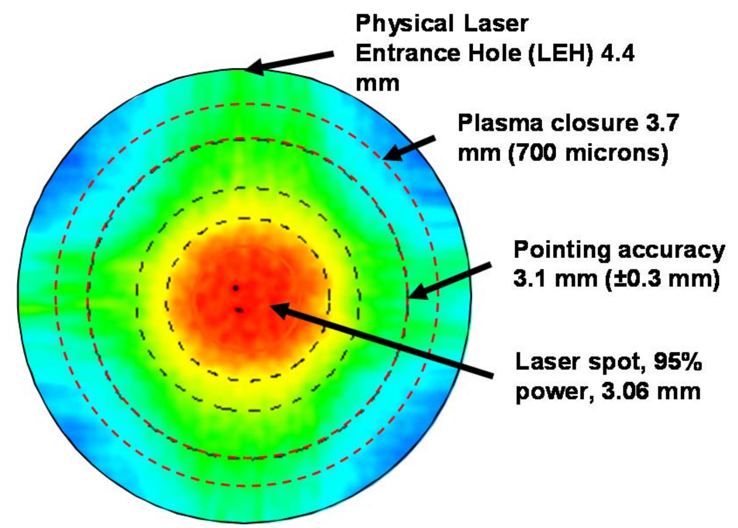
Detailed propagation simulation (based on measured NIF optics aberrations) shows excellent performance

Beam contrast at the final Fresnel optic is reasonable



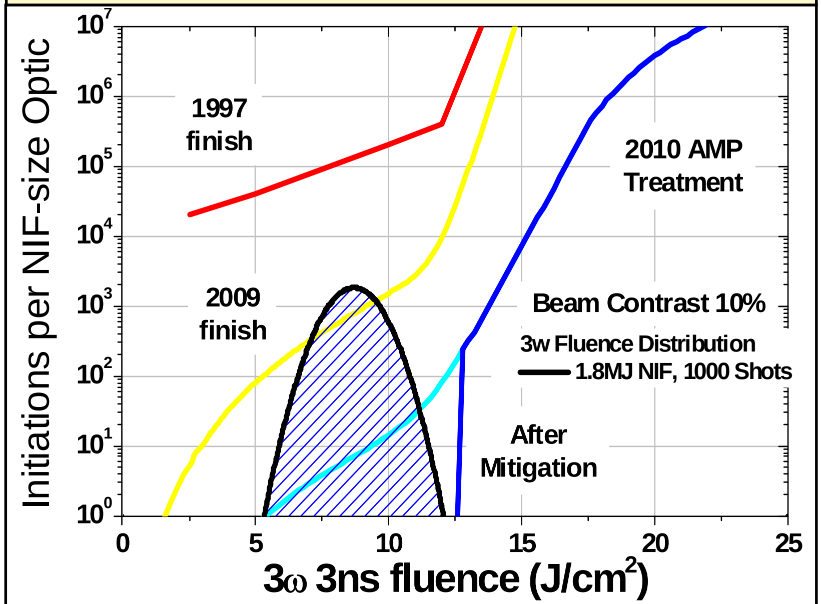
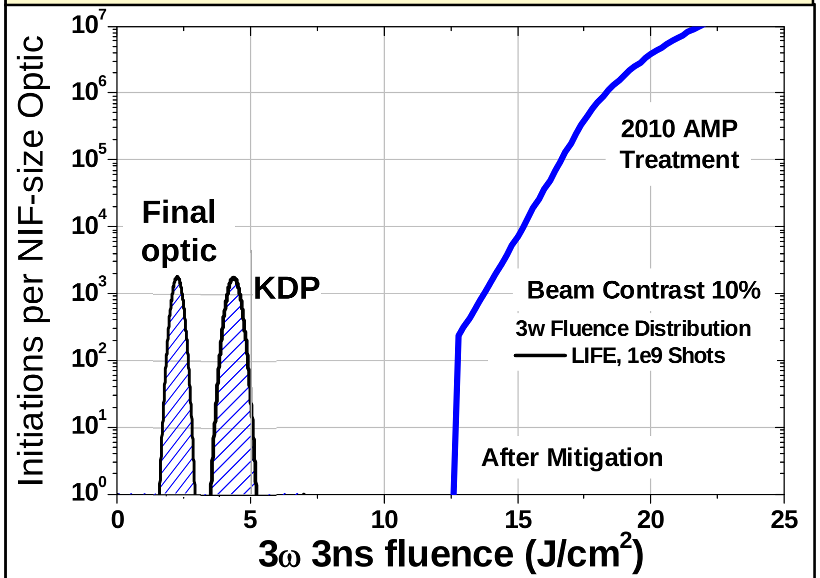
Energy = 5.5 kJ
Mean fluence = 1.55 J/cm^2
Contrast = 6.5%

Focal spot at hohlraum clears the laser entrance hole



Outer illumination cone shown with allowances for pointing/plasma closure

3ω optical damage can be mitigated using existing NIF technologies and fluence scaling

Fused Silica Lenses	Fused Silica Lenses
	
Tremendous progress has been made improving the damage resistance of optics for NIF	LIFE: average fluence reduced by >2X to add margin against modulation for high average power

NIF capability in a very small box: LIFE high average power laser architecture attributes

Provides efficiency (~18%) at high repetition rate (16 Hz)

- High Brightness efficiency diode pump arrays
- Helium gas-cooled amplifiers
- High efficiency harmonic conversion using pulse splitting

Will be built with existing materials

- Glass slabs: thermal birefringence compensated by architecture
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Designed for high availability operation

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- Optics preparation to mitigate damage

Suitable for remote (off-site) manufacturing

- Modular beamlines permit hot-swapping
- Separation of laser manufacturing & power generation operations

LIFE

LIFE laser/laser materials team

Bob Deri
Andy Bayramian
Glenn Beer
Chuck Boley
Jeff Bude
Amber Bullington
Diana Chen
Al Erlandson
Steve Fulkerson
Glenn Huete
Travis Lange
Rod Lanning
Mark Henesian
Ken Manes
Naresh Mehta
Shahida Rana
Margareta Rehak
Sam Rodriguez
Kathleen Schaffers
Mary Spaeth
Chris Stolz
Tayyab Suratwala
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Steve Telford