Lawrence Livermore National Laboratory

Laser Technologies for the Realization of a Photon Collider

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Photon colliders require lasers with high peak power, high average power and near diffraction limited spots

- High peak power
  - Each pulse is 5 Joules in 1 ps = 5 TW peak

- High average power
  - ILC or CLIC have about 15,000 electron bunches per second
  - 5 Joules x 15,000 bunches / second = 75 kW average power

- Near diffraction limit
  - Laser spot sizes are typically much larger than the electron bunch size
  - Only about laser 1 in 10^9 laser photons are used
    - potential to decrease required laser power by reusing laser pulses

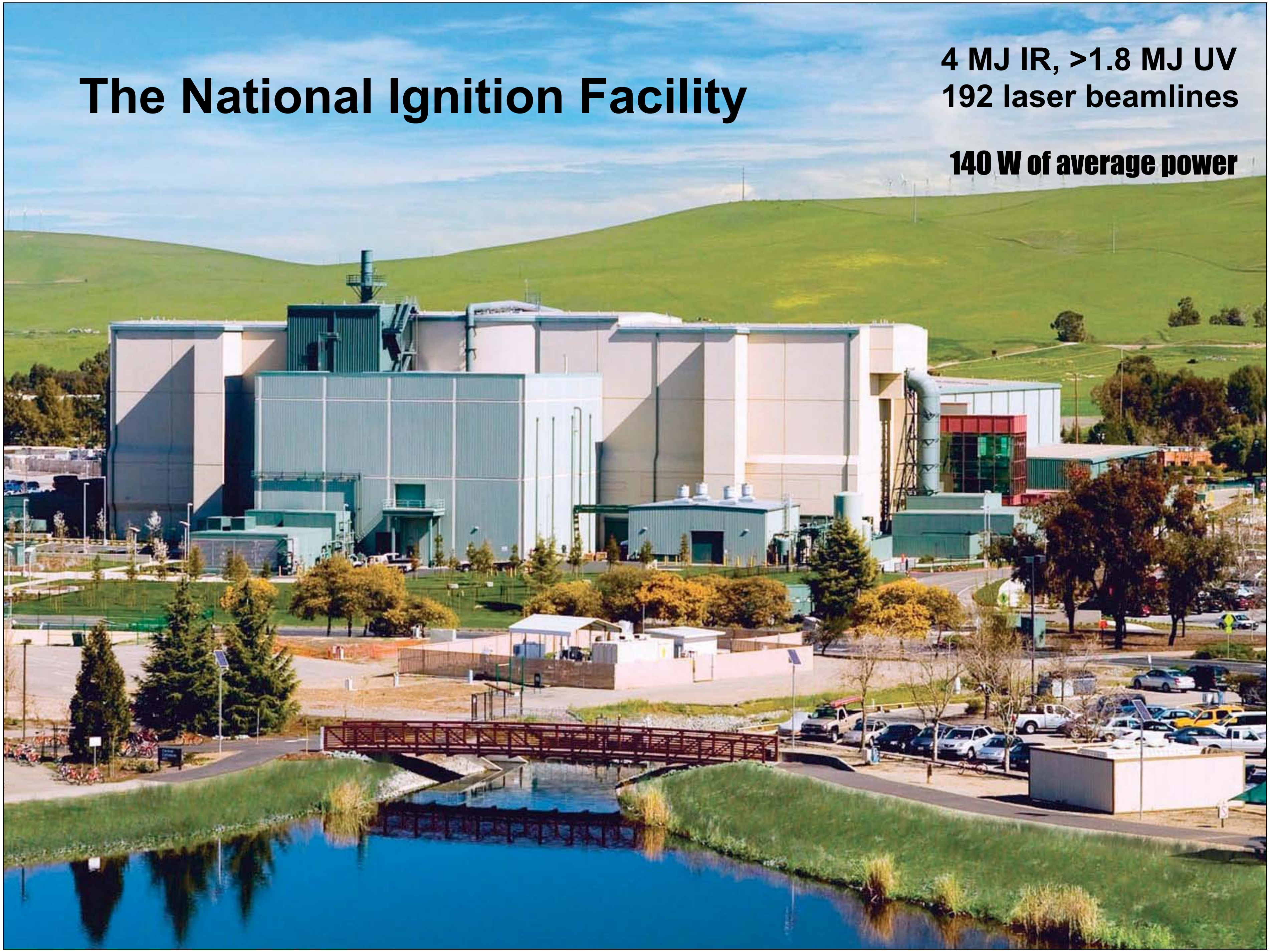
While no laser has achieved these parameters yet, the technology to do this is now within reach.

LLNL has been working on lasers for Inertial Confinement Fusion for decades

- National Ignition Facility - NIF
  - demonstration of fusion
  - high power single shot lasers
    - high peak power
    - low average power, fires once every 8 hours

- Laser Initiated Fusion Energy - LIFE
  - follow-on project for power plant design based on NIF
  - high peak and average power lasers
    - enabling technologies have been in development for the past decade (MERCURY project)

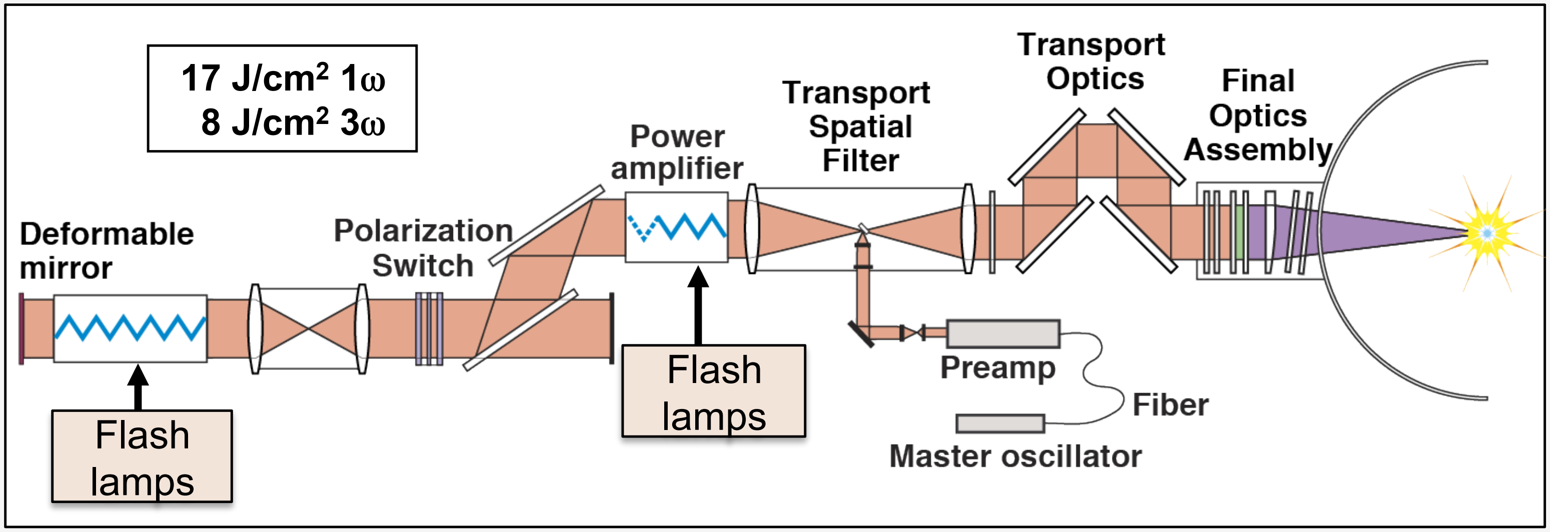
- Laser status presented here was shown at HF2013 (LLNL-PRES-601872)


The National Ignition Facility
4 MJ IR, >1.8 MJ UV
192 laser beamlines
140 W of average power

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

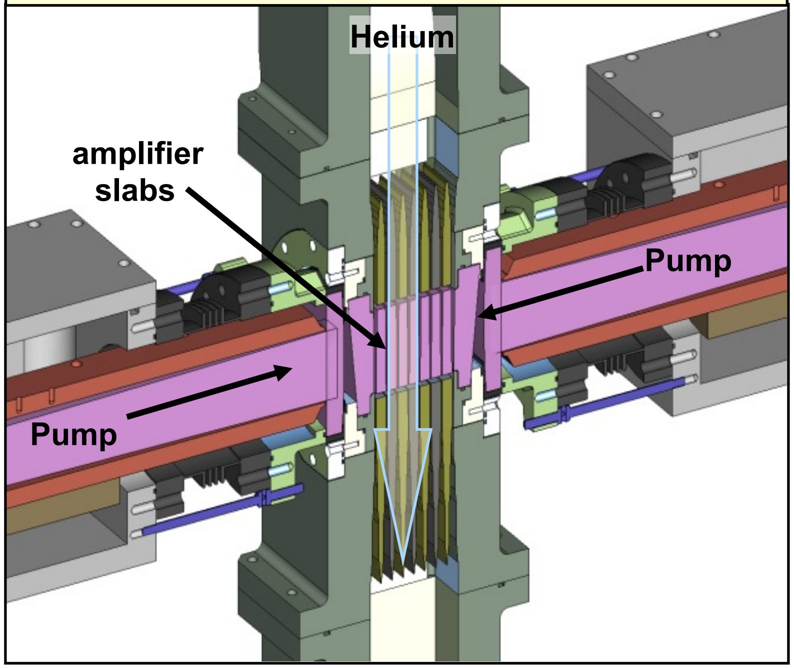
Coupling demonstration to full-scale IFE target

Moving from NIF to LIFE requires new technology to handle the high average power

- Helium flow cooling to remove heat from the amplifiers
- Diode pumping to increase the efficiency for converting wall plug power to laser light

Face cooling of the amplifier slabs minimizes thermal distortion of the crystals

Gas Cooled Amplifier Head



Details

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

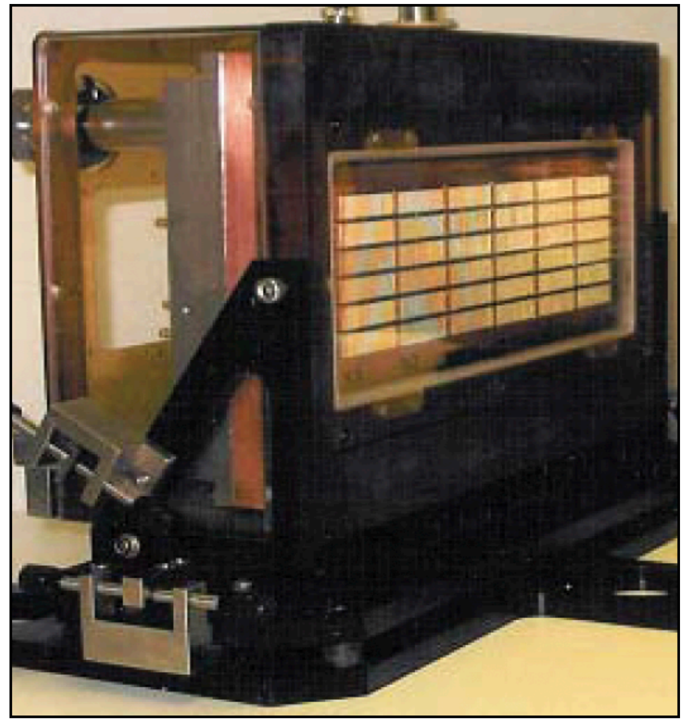
This amplifier design was prototyped and thermal / gas cooling codes benchmarked on the Mercury laser system

Diodes produce light only at the pump frequency of the laser crystal

Flashlamps have a broad spectrum

Around 1% conversion efficiency

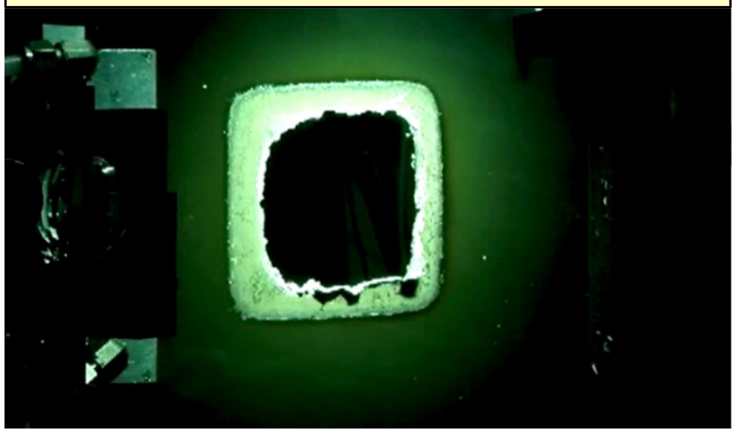
Diodes are tuned to the crystal



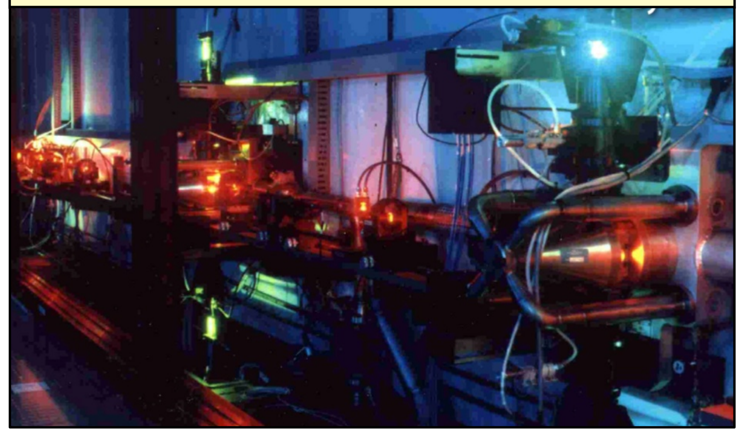
Can achieve 18% conversion efficiency

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

25 kW high average power laser



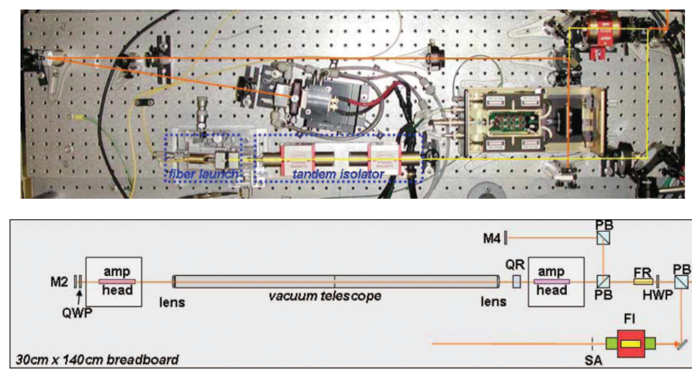
AVLIS 24/7 operational laser



600W, 10 Hz Mercury Laser

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

300 Hz, 38 W Pulse Amplifier

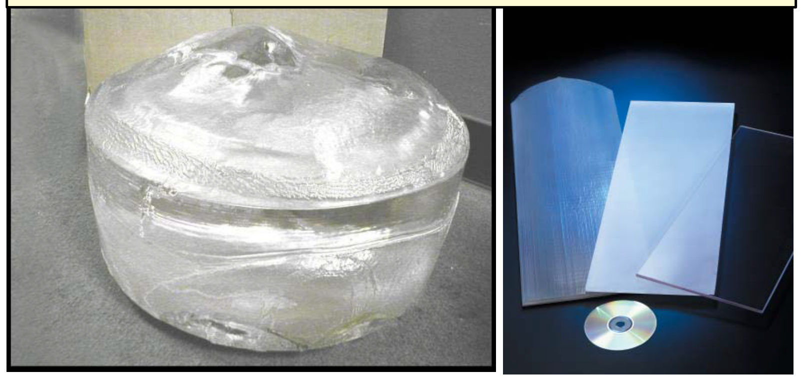


J. Honig, et. al, *Appl. Opt.* 46, 3269 (2007)

The materials chosen for the life laser are based on today's ability to meet near term build requirements

Nd^{3+}: phosphate laser glass

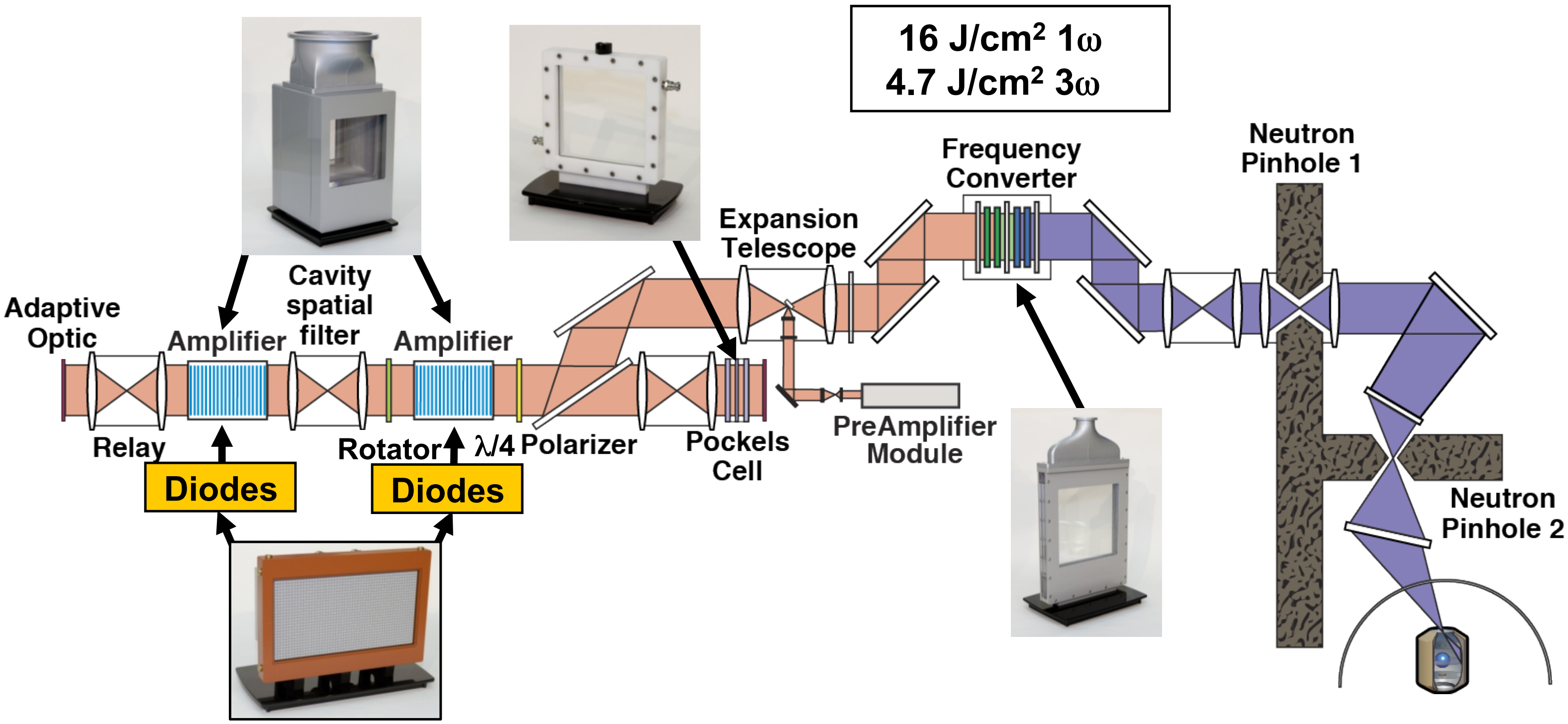
HEM Sapphire & EFG Sapphire waveplates



Quartz crystal rotators

KDP and DKDP frequency conversion crystals

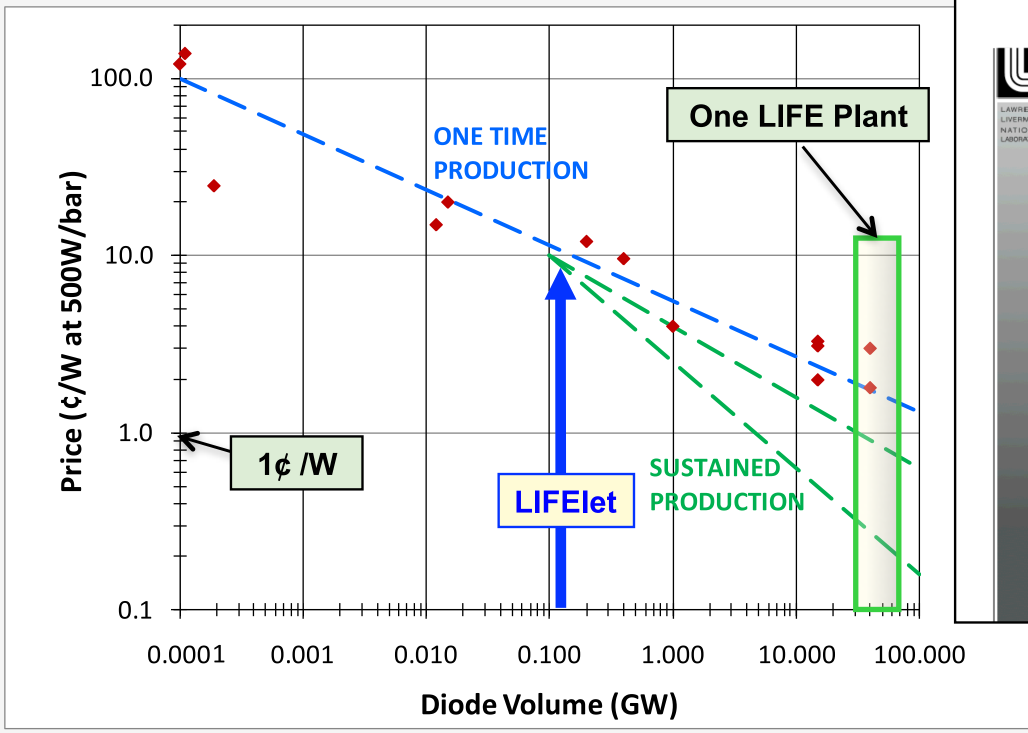
LIFE combines the NIF architecture with high efficiency, high average power technology

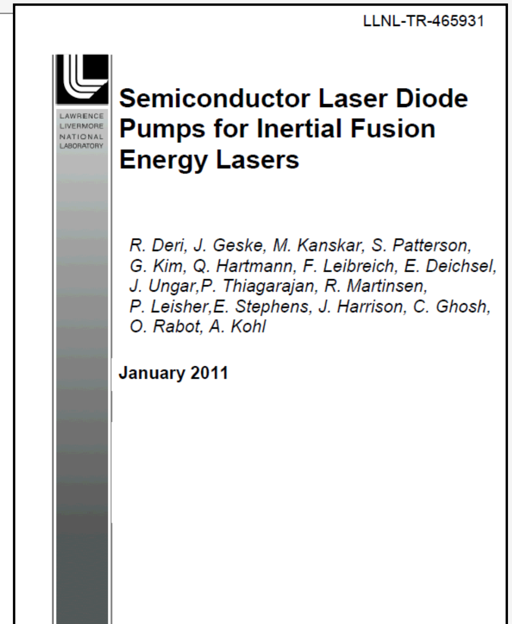


Diode pumps	→	high efficiency (18%)
Helium cooled amps	→	high repetition rate (16 Hz) with low stress
Normal amp slabs	→	compensated thermal birefringence, compact amp
Passive switching	→	performs at repetition rate
Lower output fluence	→	less susceptible to optical damage

Diode costs are the main capital cost in the system

- 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

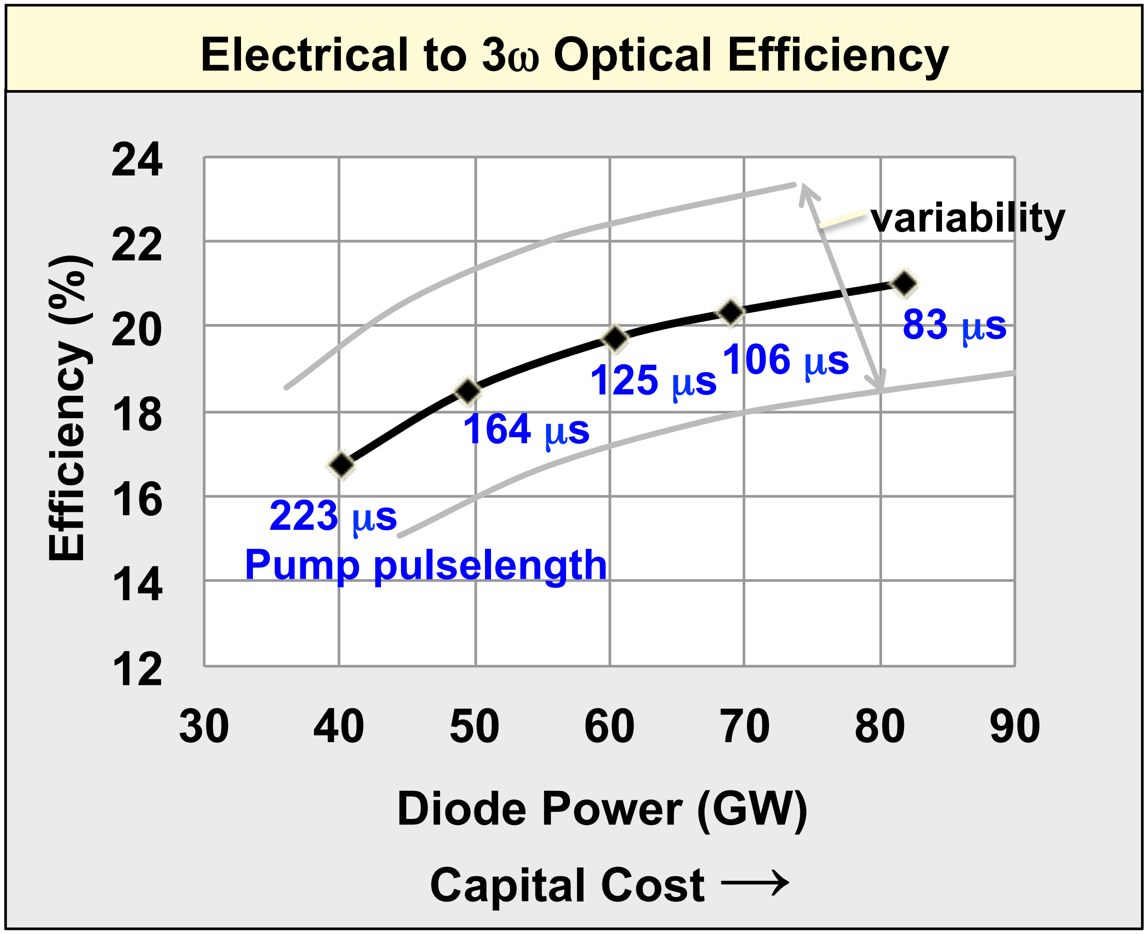
January 2011

- 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

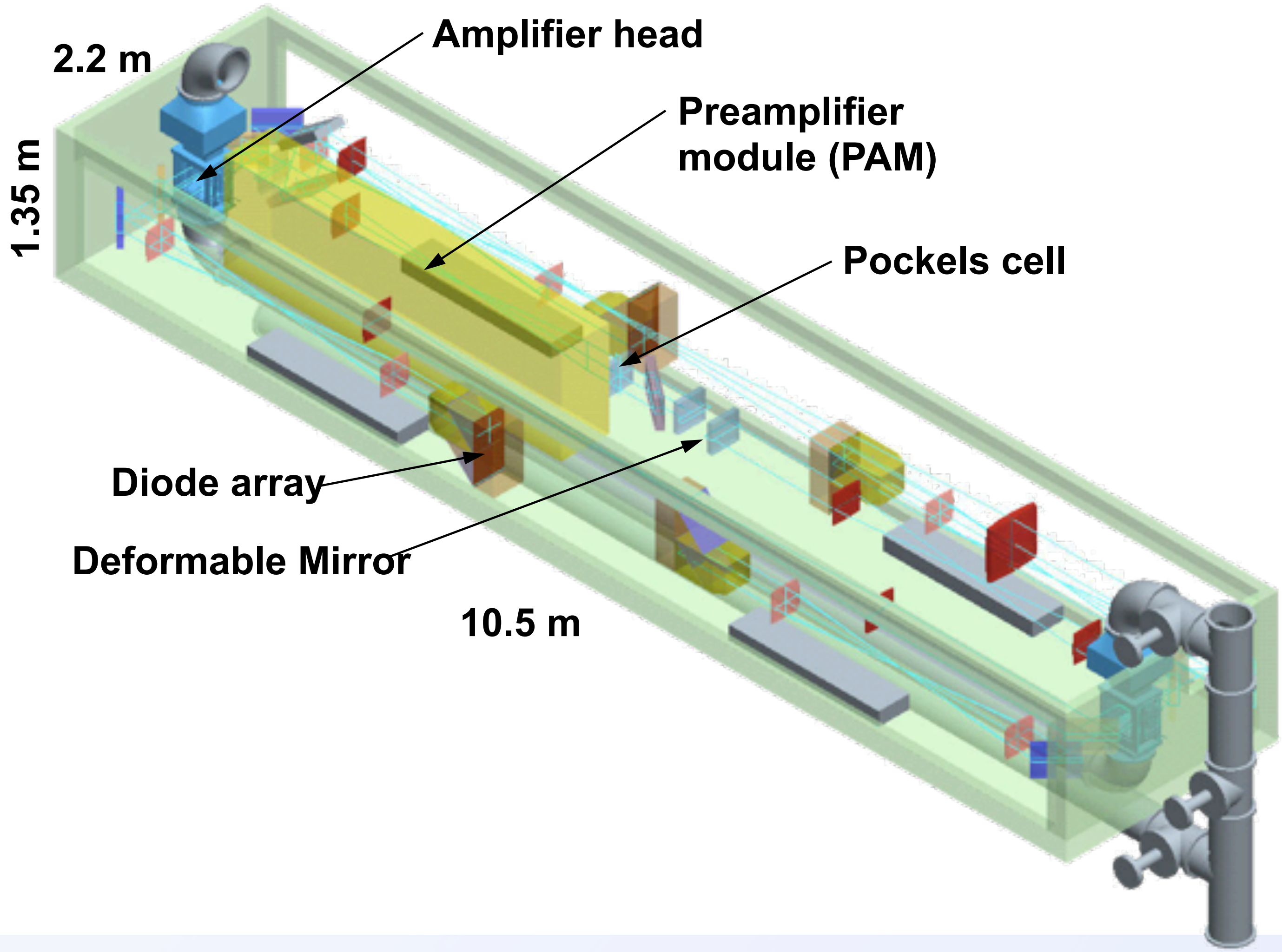
Diode costs for 1 beamline ~ $2.3M

LIFElet (1st beamline) $0.1/W
diodes for 1 beamline $13M

There is a tradeoff between capital cost and conversion efficiency



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

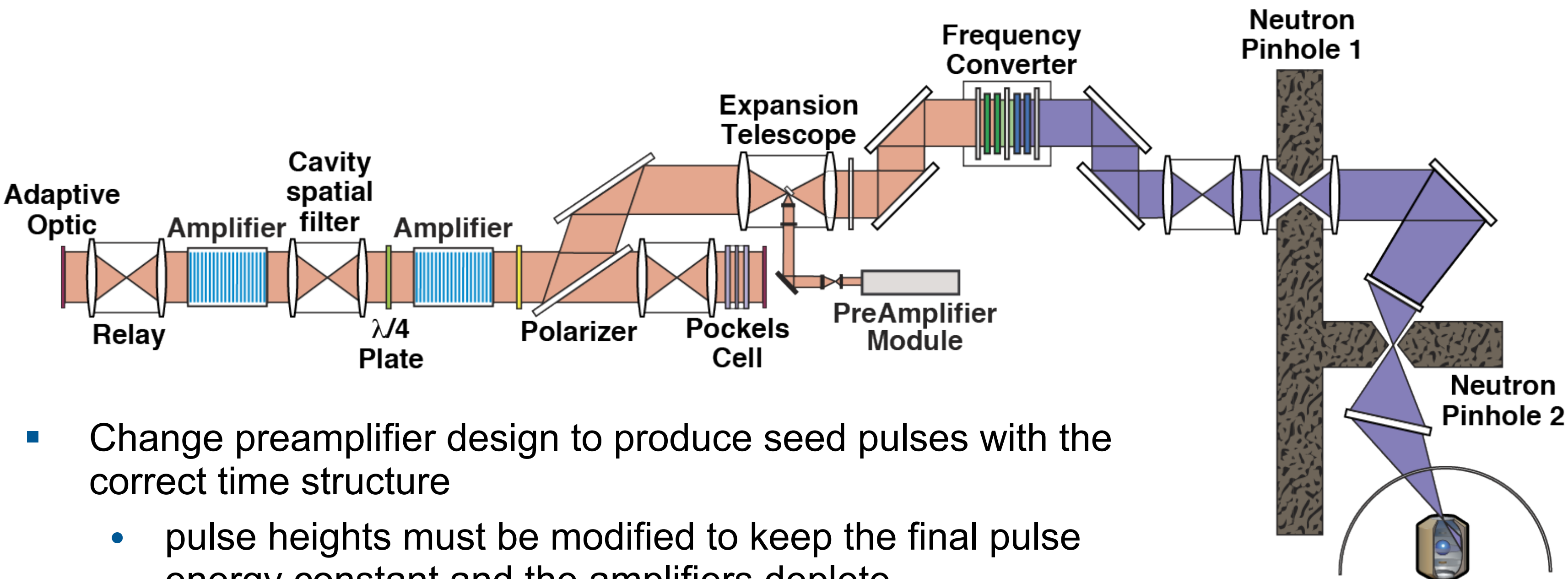
ICF has provided us with a set of technologies, let's steal as much as possible for a photon collider laser

- LIFE beamline
  - Pulses at 16 Hz, 8.125 kJ / pulse, 130 kW average power, ns pulse width

- What we want for the photon collider
  - ILC: Pulses at 5 Hz, 3000 pulses/train, 330 ns pulse separation, 5 J / pulse, ps pulse width
  - CLIC: Pulses at 50 Hz, 300 pulses/train, 0.5 ns pulse separation, 5 J / pulse, ps pulse width

- Average powers are comparable but pulse energy and structure is very different

Modifications to support the photon collider pulse time structure



- Change preamplifier design to produce seed pulses with the correct time structure
  - pulse heights must be modified to keep the final pulse energy constant and the amplifiers deplete
- Add a set of diffraction gratings:
  - ps -> ns for chirped pulse amplification
  - ns -> ps for post amplification compression
- Amplifier crystal must have bandwidth to support compression

All available technologies

Summary

- ICF has been busy for the last couple of decades solving our laser technology problem
- If a demonstration life beamlet is funded by the ICF program we may get a technology demonstration for free
- The LIFE laser can most likely be adapted to serve as a Photon Collider laser
  - amplifier cooling is not a problem
  - a real design of the modifications necessary should be done by the laser designers
  - average power on the optical components might be a problem