Lawrence Livermore National Laboratory

Extrapolating Current Laser Technology for a Sapphire Laser System

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UCRL-XXXX-12345

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

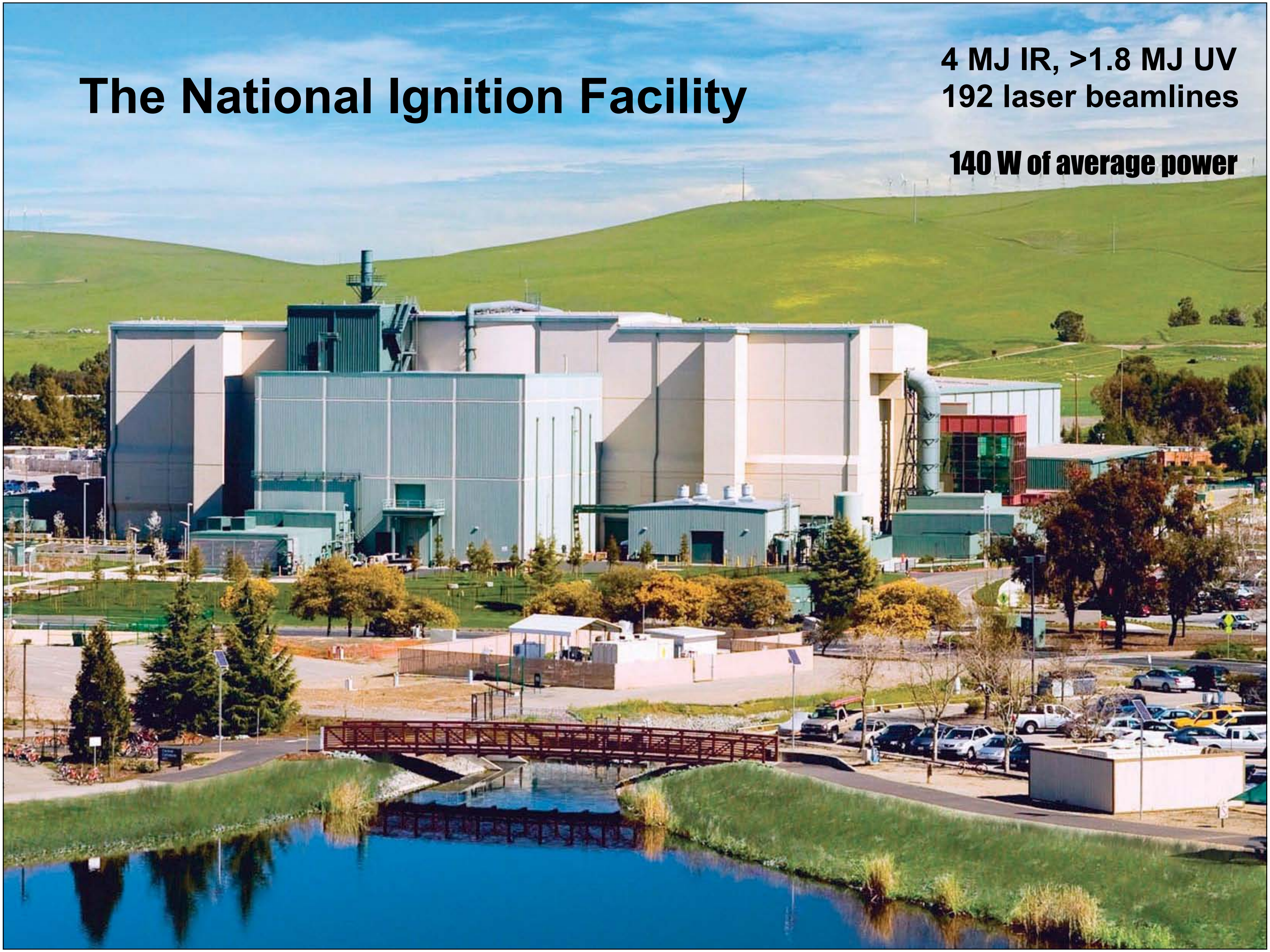
- Laser Initiated Fusion Energy - LIFE
  - follow-on project for power plant design based on NIF
  - high peak and average power lasers
    - enabling technologies have been in development for the past decade (MERCURY project)

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

Photon colliders need lasers with both high peak and average power

- Every electron bunch must be hit with a ~5J - ps laser pulse
  - ILC, CLIC have ~15,000 bunch/s = 75 kW average laser power
  - Sapphire has 200,000 bunch/s = 1 MW average laser power
  - (each x2 for two beamlines)

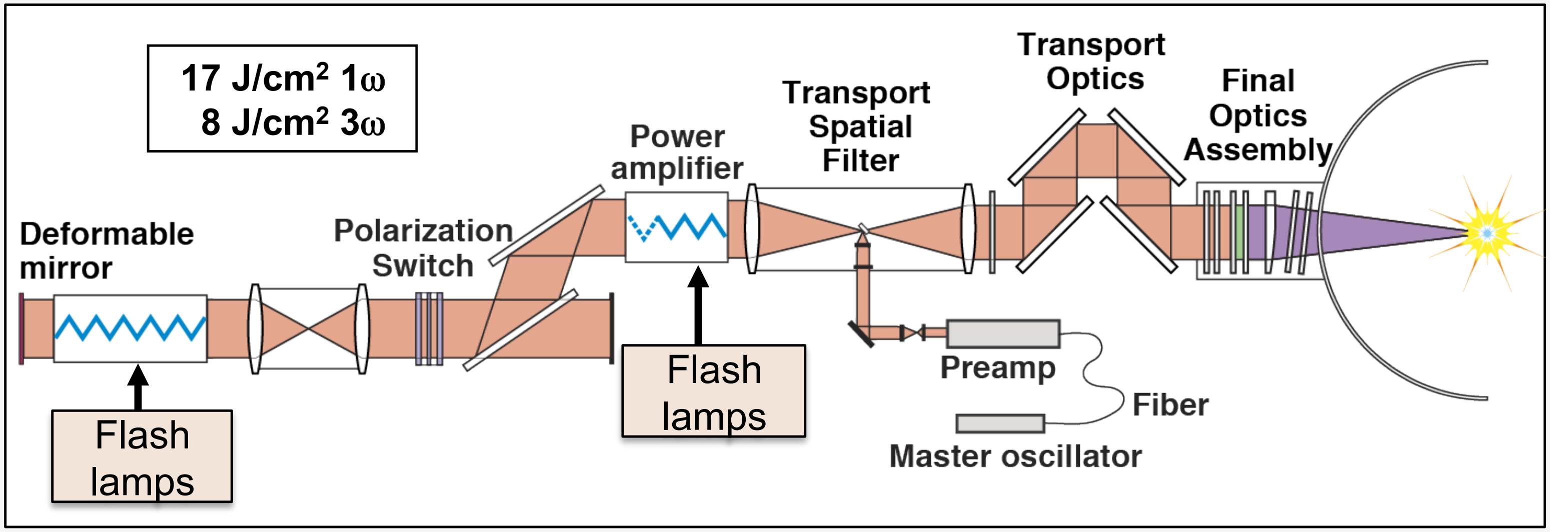
- Laser pulses can be recirculated to lower the necessary average power


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

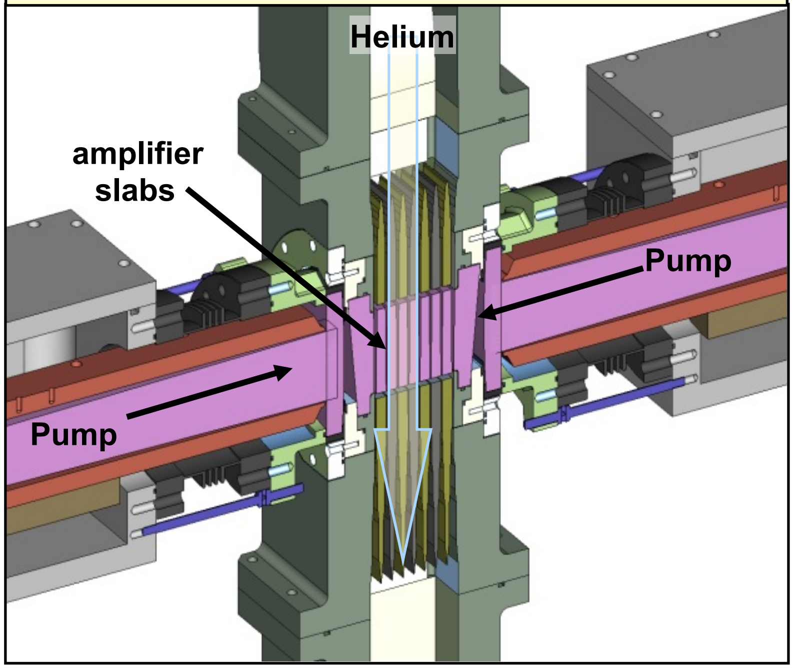
Coupling demonstration to full-scale IFE target

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**

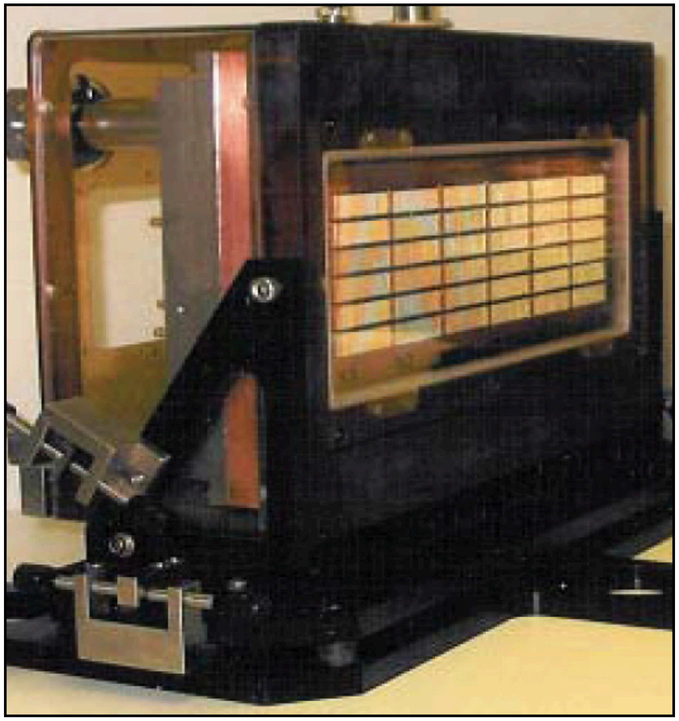
This amplifier design was prototyped and thermal / gas cooling codes benchmarked on the Mercury laser system

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

Flashlamps have a broad spectrum

Around 1% conversion efficiency

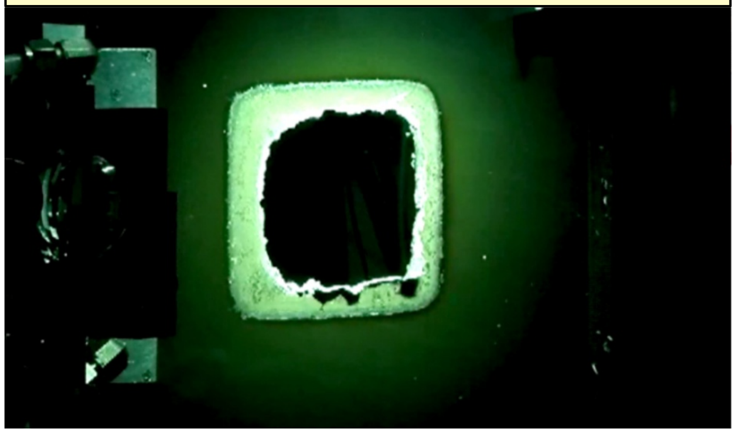
Diodes are tuned to the crystal



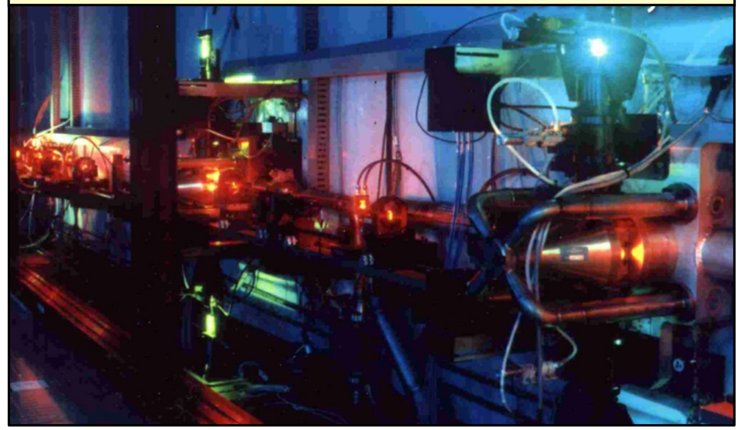
Can achieve 18% conversion efficiency

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

25 kW high average power laser



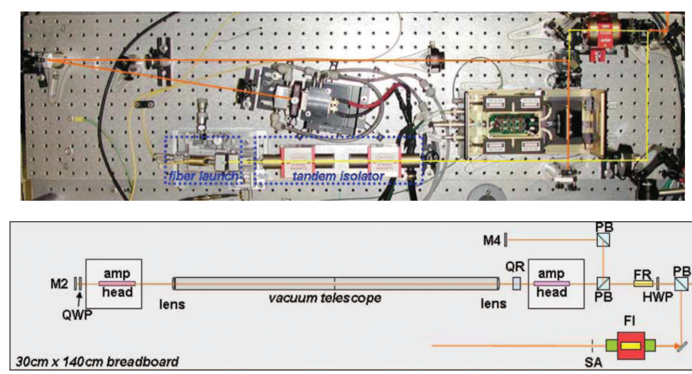
AVLIS 24/7 operational laser



600W, 10 Hz Mercury Laser

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

300 Hz, 38 W Pulse Amplifier

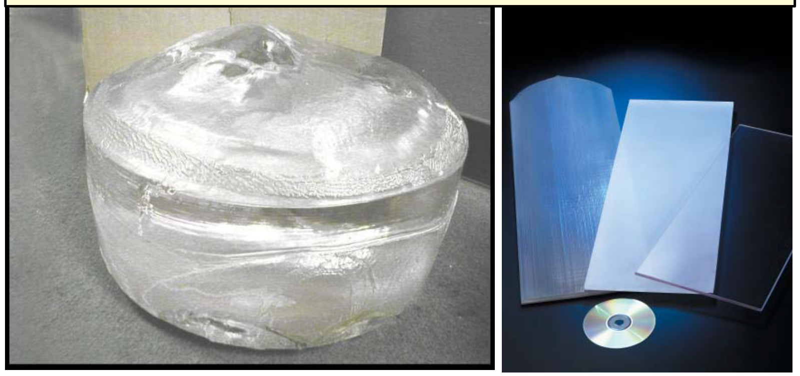


J. Honig, et. al, *Appl. Opt.* 46, 3269 (2007)

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

Nd^{3+}: phosphate laser glass

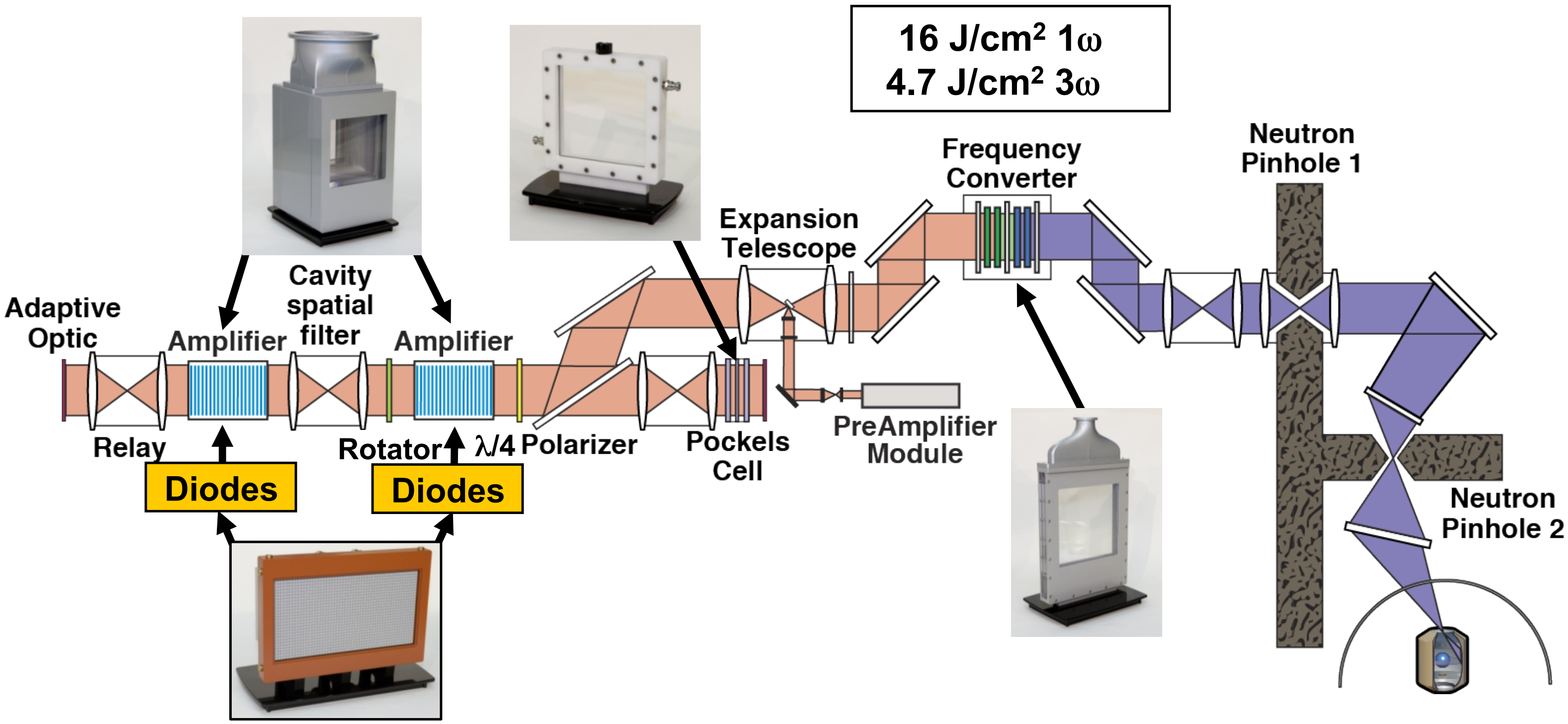
HEM Sapphire & EFG Sapphire waveplates



Quartz crystal rotators

KDP and DKDP frequency conversion crystals

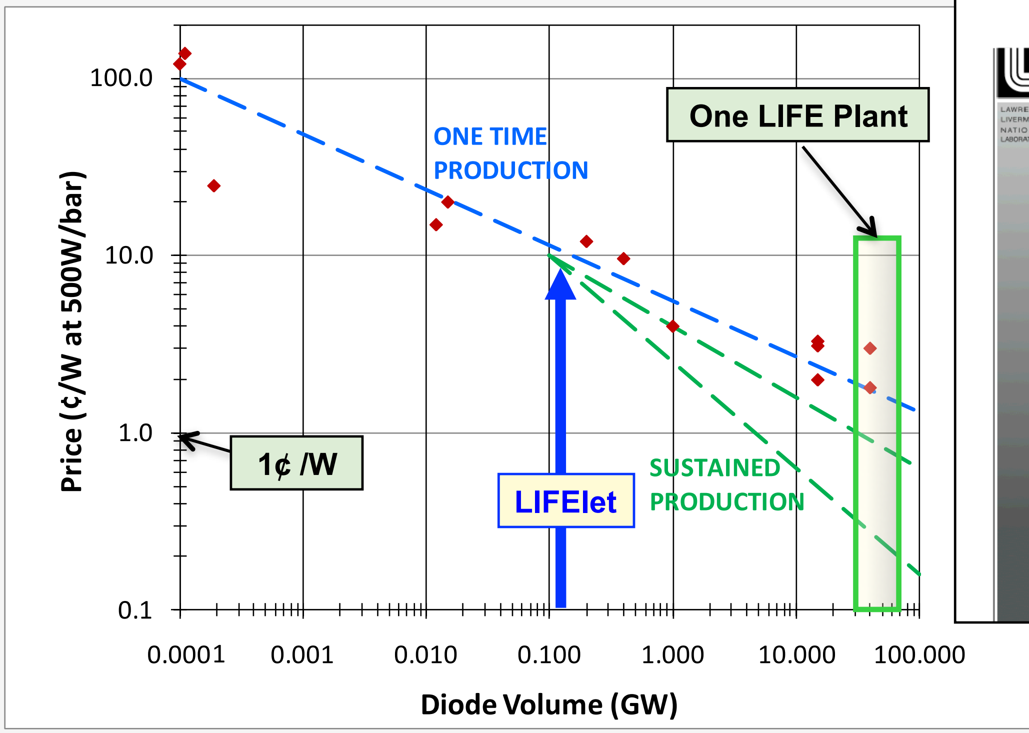
LIFE combines the NIF architecture with high efficiency, high average power technology

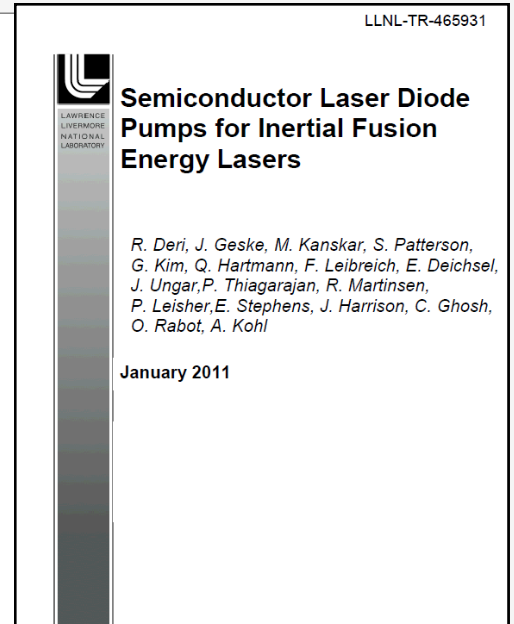


Diode pumps	→	high efficiency (18%)
Helium cooled amps	→	high repetition rate (16 Hz) with low stress
Normal amp slabs	→	compensated thermal birefringence, compact amp
Passive switching	→	performs at repetition rate
Lower output fluence	→	less susceptible to optical damage

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

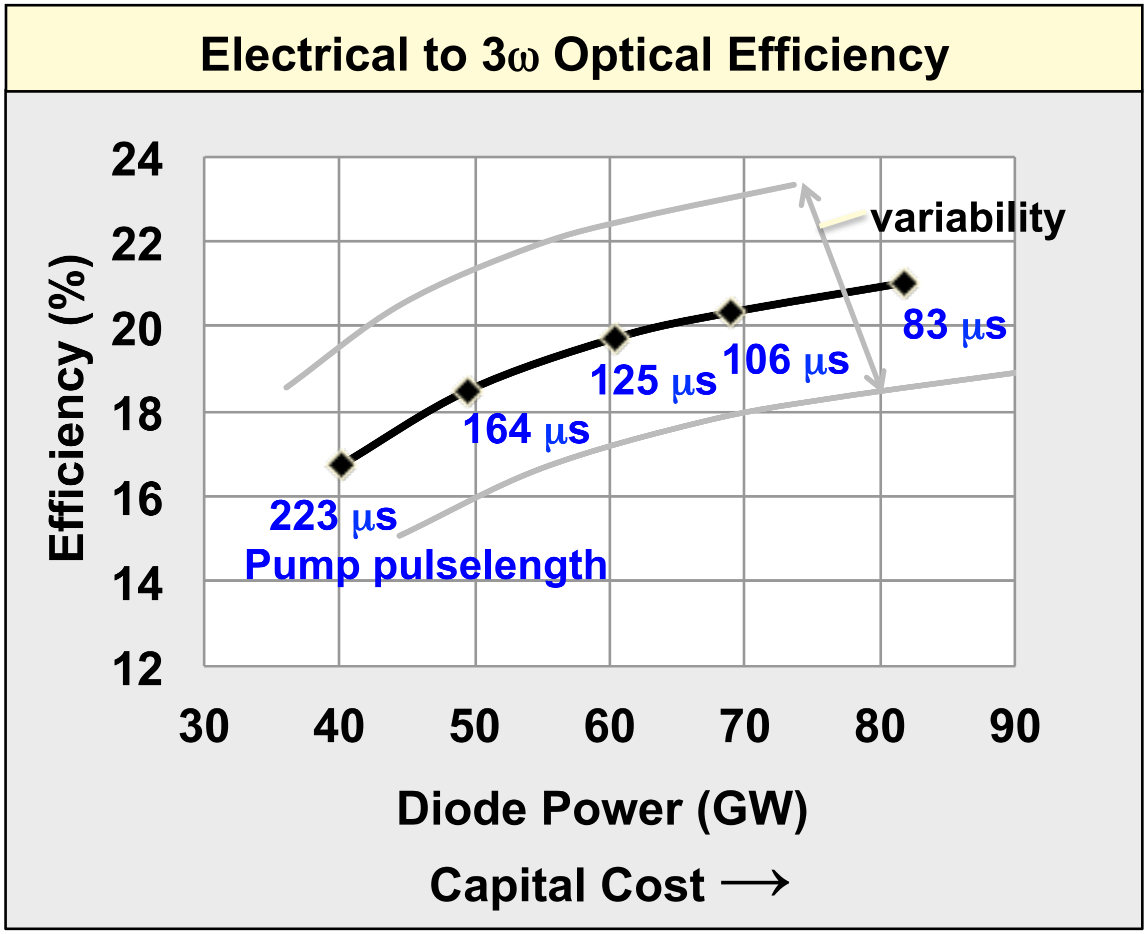
January 2011

- 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

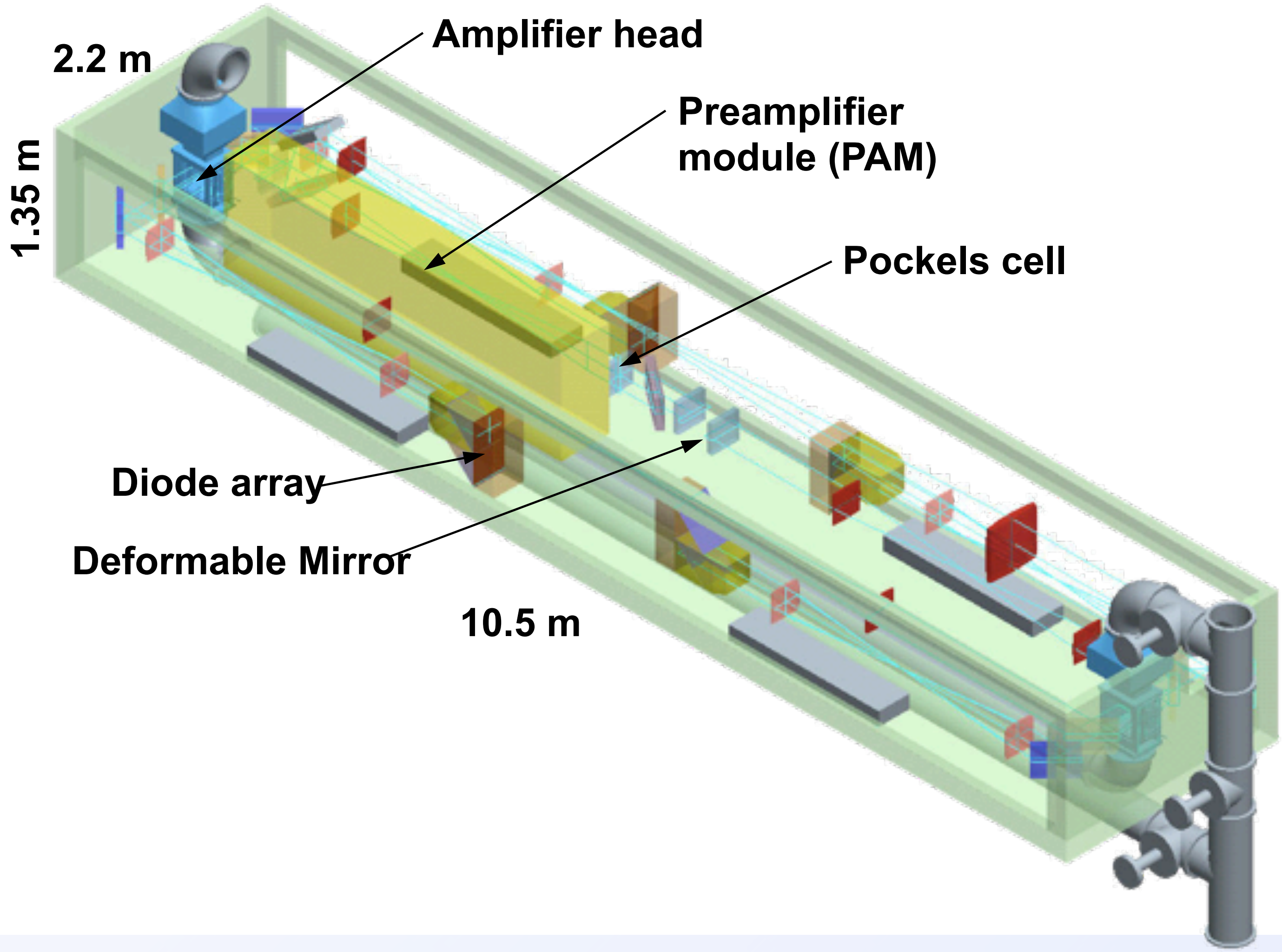
Diode costs for 1 beamline ~ $2.3M

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

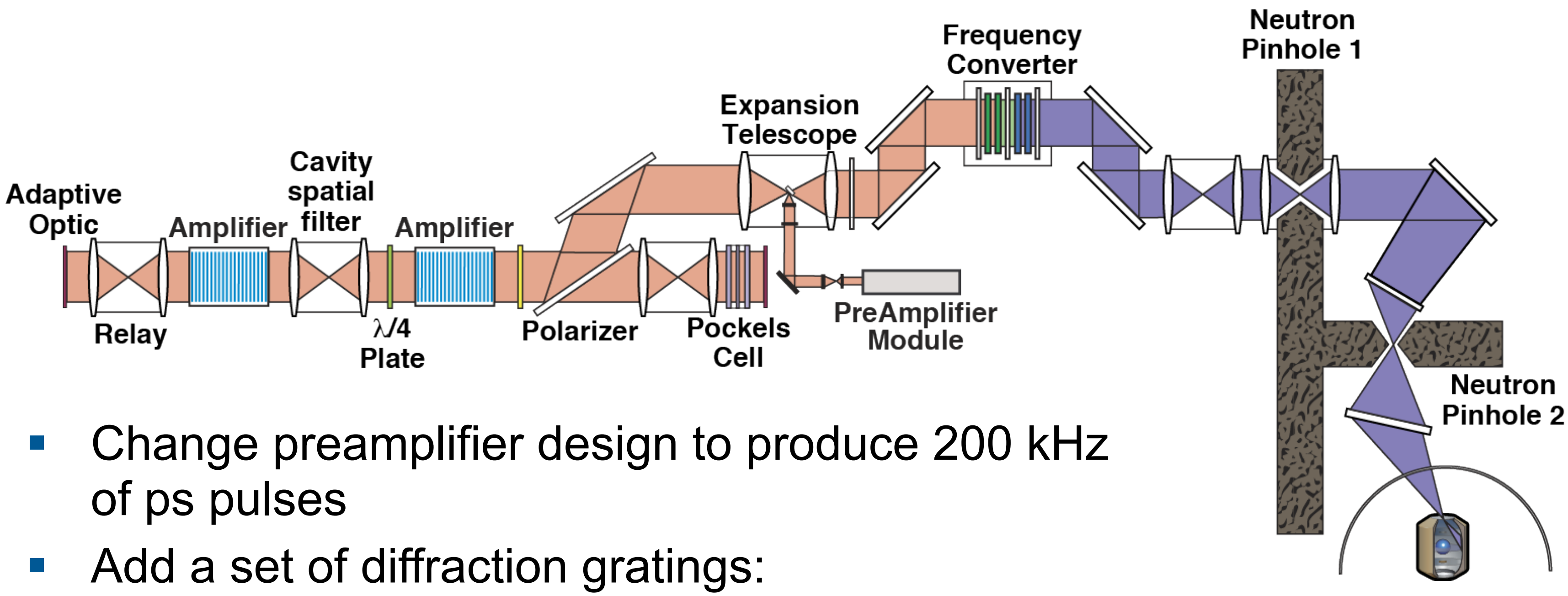


LIFE Box in NIF Laser Bay

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

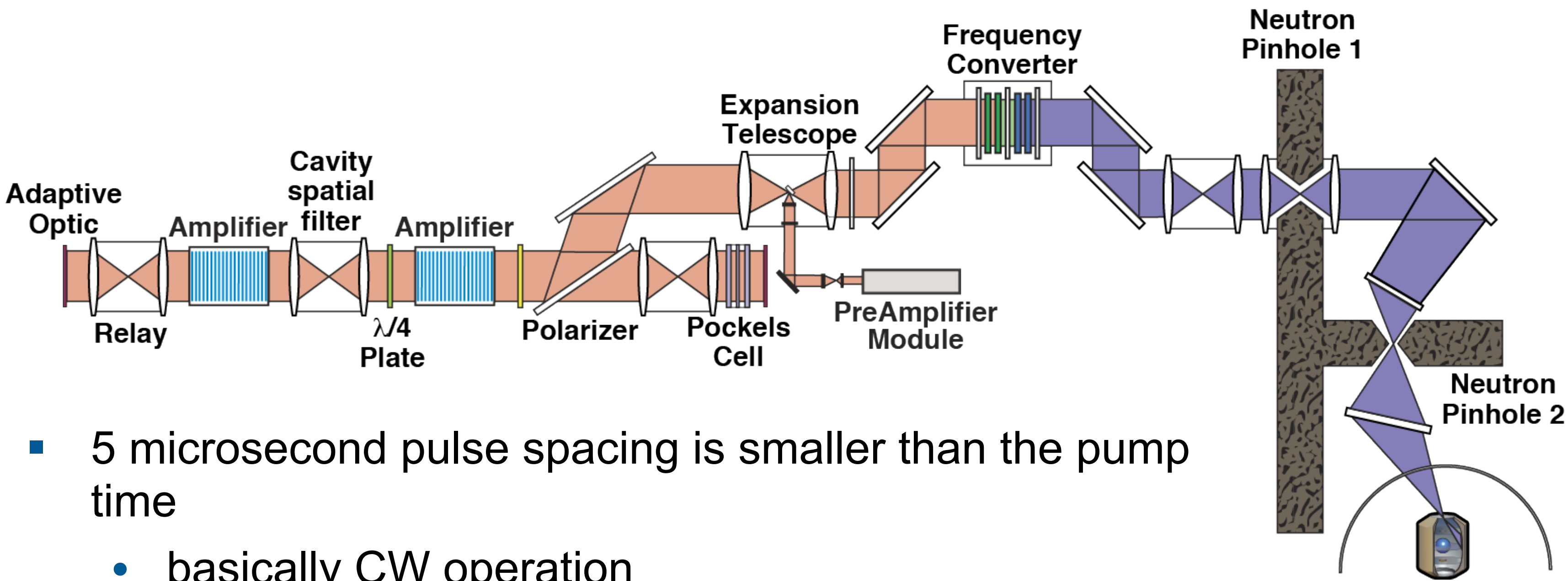
- LIFE beamline
  - Pulses at 16 Hz, 8.125 kJ / pulse, 130 kW average power, ns pulse width
- What we want for Sapphire
  - Pulses at 200 kHz, 5 J / pulse, 1000 kW average power, ps pulse width for a single pass system
  - Pulses at 200 kHz, 0.05 J / pulse, 10 kW average power, ps pulse width if we have a recirculating cavity with Q=100
- Average powers are comparable but pulse energy and structure is very different

Modifications to support 200 kHz of ps pulses



- Change preamplifier design to produce 200 kHz of ps pulses
- 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
- Available technology

Required peak diode power goes down



- 5 microsecond pulse spacing is smaller than the pump time
  - basically CW operation
  - peak diode power -> average power
  - diode arrays must handle much more average power
- Amplifier crystals always charged
  - must control amplified spontaneous emission

A single pass system would have a MW of average power (times 2 beamlines)

- 10 life beam lines running at 20 kHz
  - each with 100 kW of average power
  - interleave pulses to create 200 kHz
    - 5 micro-second gap is plenty for Pockel's cells to switch in the pulses

- Advantages:
  - Easier control of photon beam polarization
  - Eliminate issues with recirculating cavities
- Disadvantages:
  - Higher capital cost and energy requirements

A recirculating cavity driver would have 10 kW average power (Q=100) (times 2 beamlines)

- 1 life beam line running at 200 kHz, 0.05 J / pulse
  - 10 kW average power

- Advantages:
  - Minimized capital cost and small power requirements
- Disadvantages:
  - Phase matching requirements for the recirculating cavity
  - Recirculating cavity capital costs and operating issues
  - Reduced polarization control

Summary

- The LIFE laser can probably be adapted to serve as the SAPPHiRE laser
  - amplifier cooling is not a problem
  - how much the diode peak power can be reduced will depend on the ability to handle average power
  - a real design of the modifications necessary should be done by the laser designers