LLNL-PRES-

Progress in Diode Pumped Solid State Laser Driver Development for HAPL

Presentation to
HAPL Project
Madison, Wisconsin

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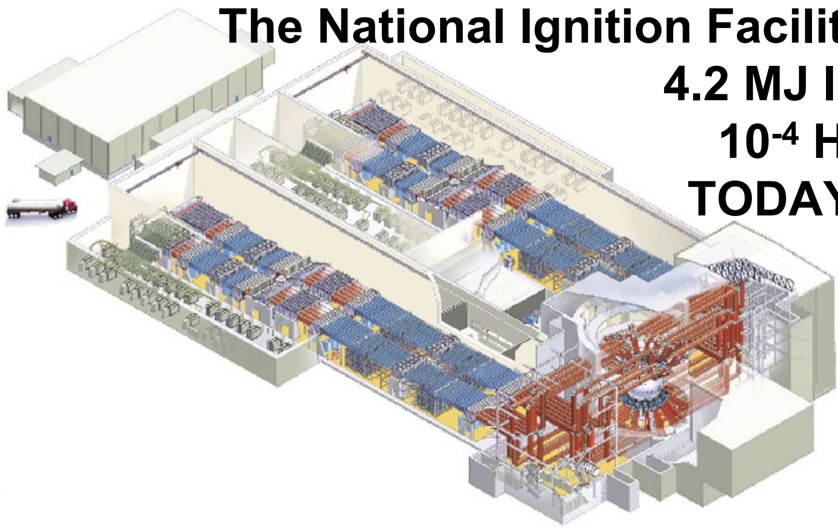
The Mercury laser is an important step from the NIF to a 10 Hz, high energy laser driver for Inertial Fusion Energy (IFE)



The National Ignition Facility
4.2 MJ IR
10^{-4} Hz
TODAY!

100J IR
10 Hz

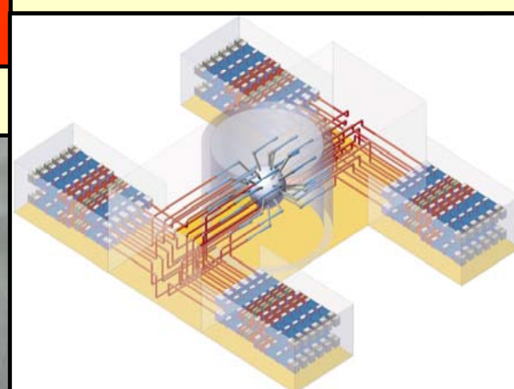
Mercury

10 kJ IR
10 Hz

IFE Beamlet

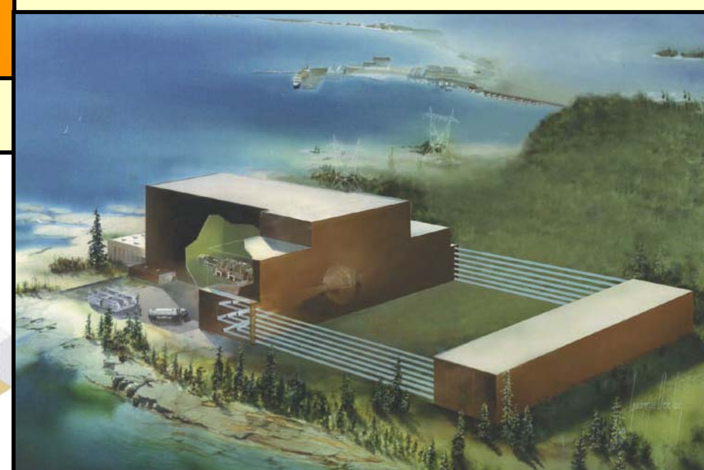
1-3 MJ Green/UV
10-20 Hz

IFE Demo

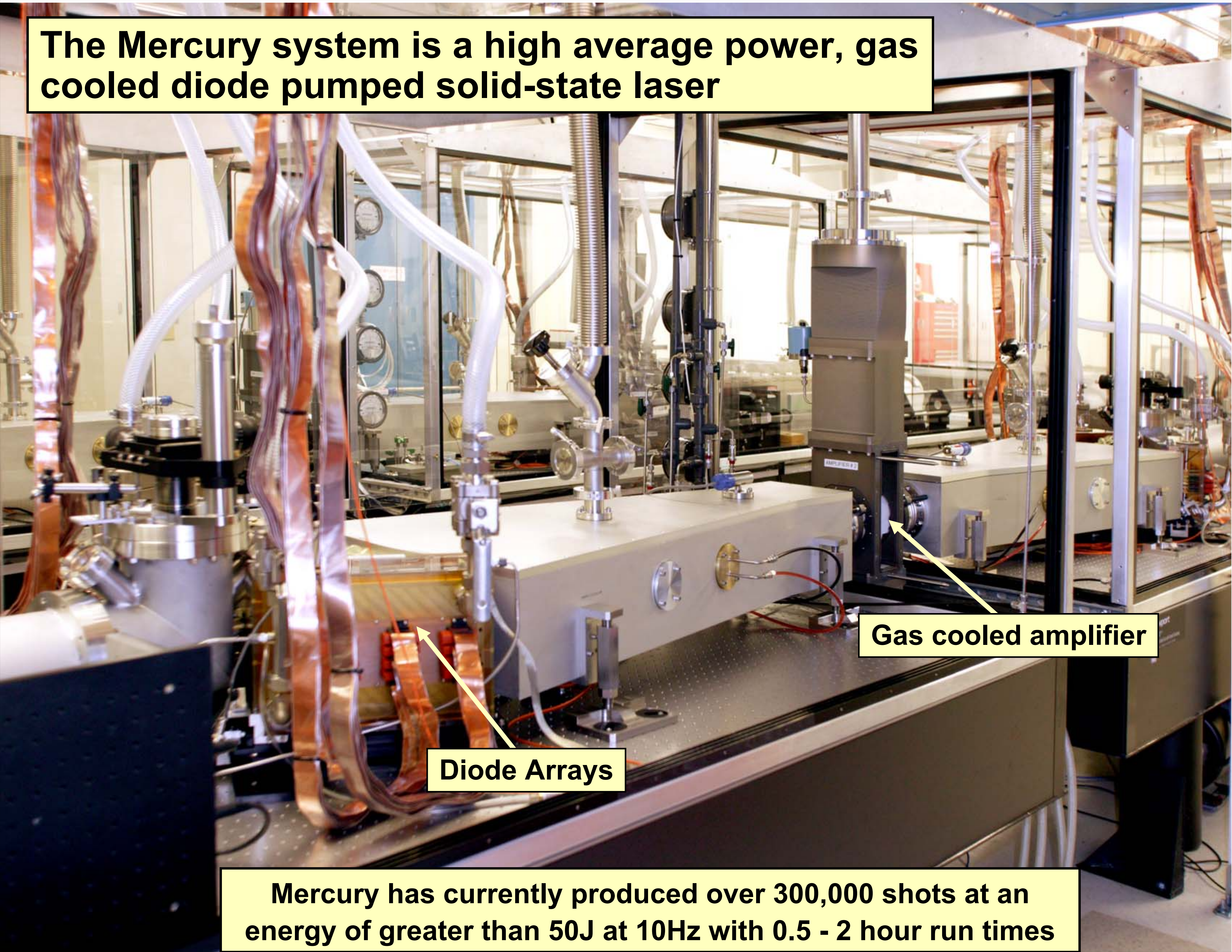


1-3 MJ Green/UV
10-20 Hz

IFE Plant



The Mercury system is a high average power, gas cooled diode pumped solid-state laser

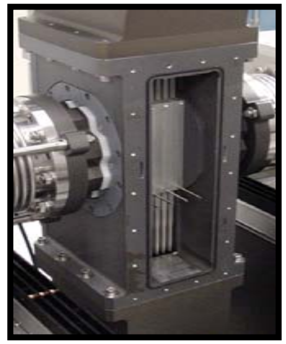


Mercury has currently produced over 300,000 shots at an energy of greater than 50J at 10Hz with 0.5 - 2 hour run times

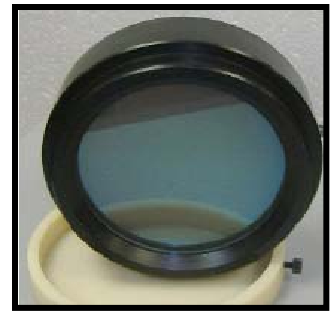
The Mercury laser employs many advanced technologies to achieve scalable, efficient, high-average-power operation

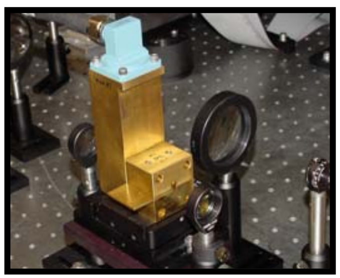
Diode Arrays

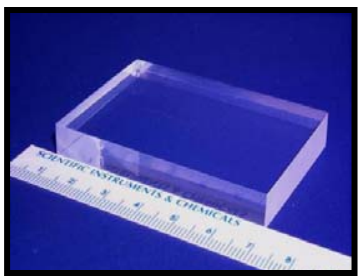
Gas Cooling

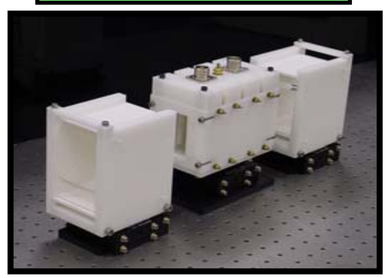


Front End → Gain Media → Pockels Cell → Adaptive Optic

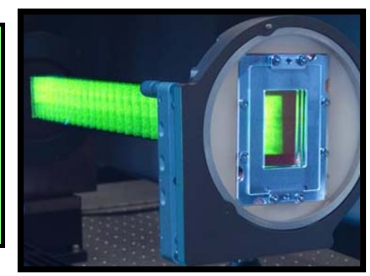








Frequency Conversion



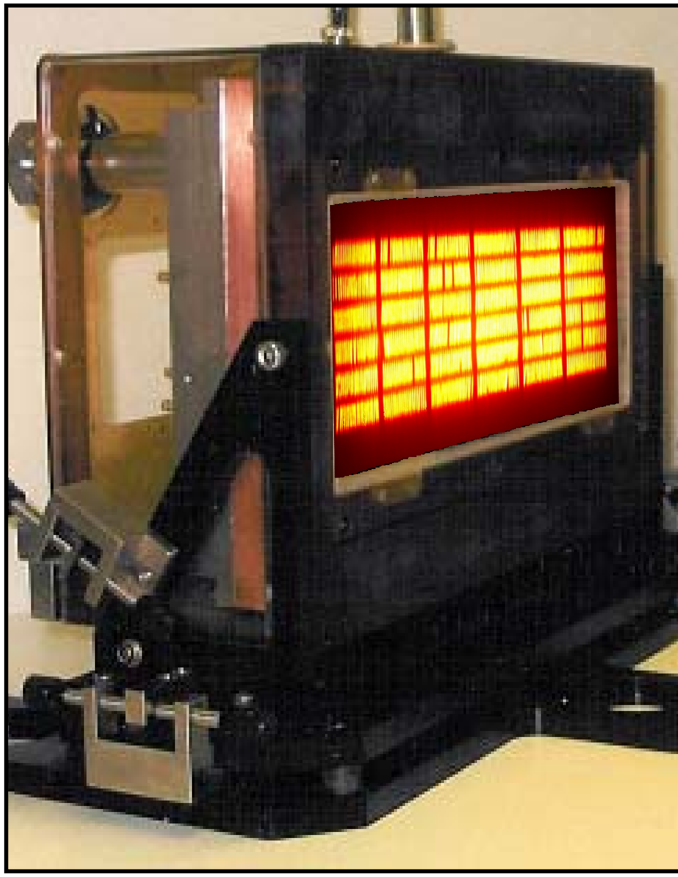
- These component technologies are "first-of-a-kind"
- Scaling and engineering are still required for implementation in IFE

Final Optic (TBD)

Chamber (TBD)

Diode Development

The Mercury diode arrays demonstrated performance consistent with IFE requirements



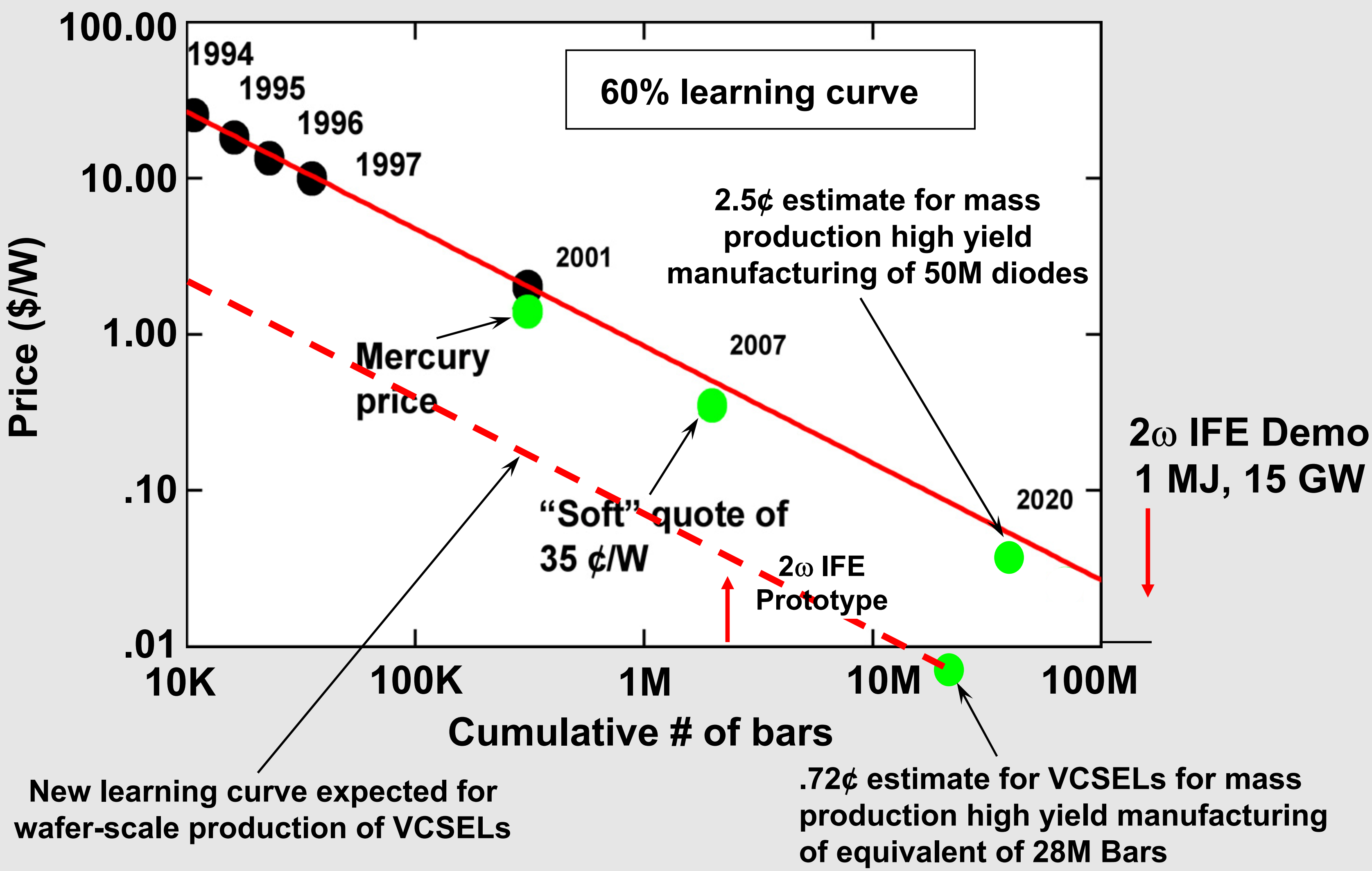
Diode tile attributes	Goal	Demonstrated Performance
Power (W/bar)	> 100	120
Reliability (shots) @ > 100 W/bar	> 2 x 10^8	> 1.4 x 10^8
System shots (8, 100-kW arrays @ 10 Hz)	> 1 x 10^6	3 x 10^6
Power droop (1 msec)	< 15 %	4.3 %
Linewidth (nm)	< 5	2.3
Integrated linewidth (nm)	< 8.5	4.1
Divergence ($mrad^2$)	< 18 x 180	15 x 140
Wallplug efficiency, η	> 50 %	45 %*

Improvements in the areas of power, reliability, and wallplug efficiency will reduce the system cost and provide an attractive power source

* Limited by 2002 diode bar material, current diode bars η > 60%

Diode requirements for a single IFE demonstration reactor could easily drive costs to < $0.01/Watt

Cost Study for Diodes from Industry at High Yields



Front End Development

We have built a stable and reliable front end laser that addresses our pulse requirements

	Laser Performance	Goal	Status
Energy	Energy (mJ)	≥ 500	550
	RMS Stability (%)	≤ 1	0.78
	Signal to noise (ASE)	≥ 10000:1	1,000,000:1
Temporal	Shaping contrast	≥ 80:1	150:1
	Intensity fluctuations (%)	≤ 5	2.2
	Jitter (ps)	≤ 300	260
Spectral	Bandwidth (GHz)	≥ 240	240
	Stability (GHz)	≤ 3	0.08
	Amplitude and phase shaping	≥ 100:1	300:1

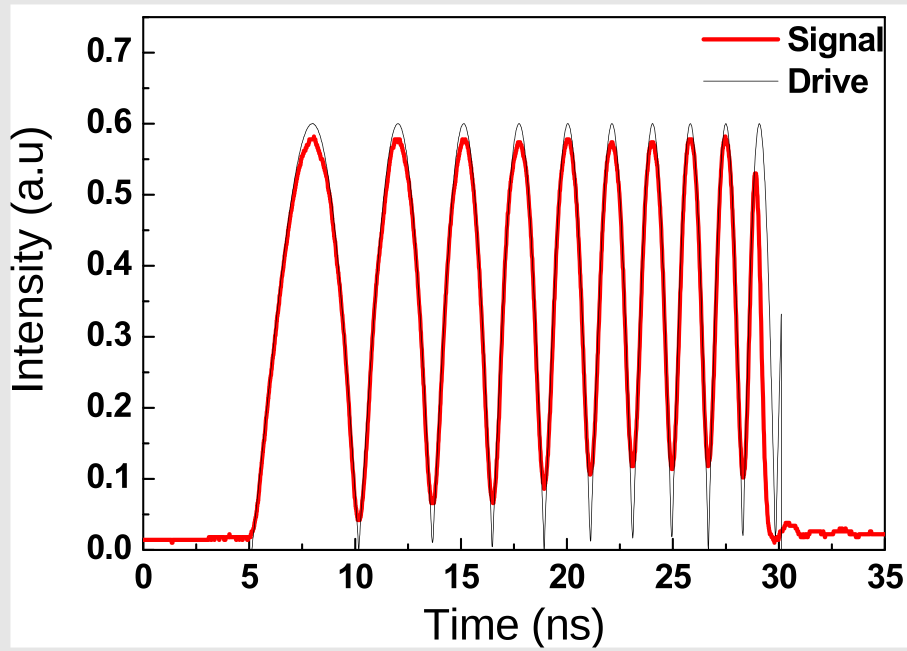
Our control system allows the laser to be run with minimal user intervention

An arbitrary waveform generator provides shaped seed pulses

Temporal shaping:

- **Dual stage electro-optic modulator**
- **96 temporal adjustments across 24 ns**
- **250 ps resolution**

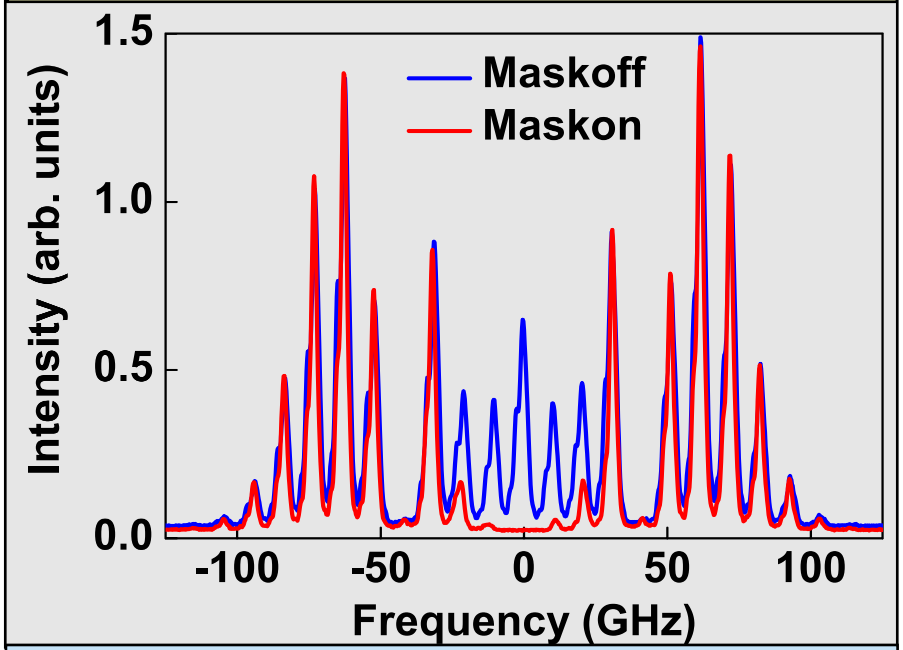
Temporal shaping example



Active temporal waveform control allows for correction of square pulse distortion

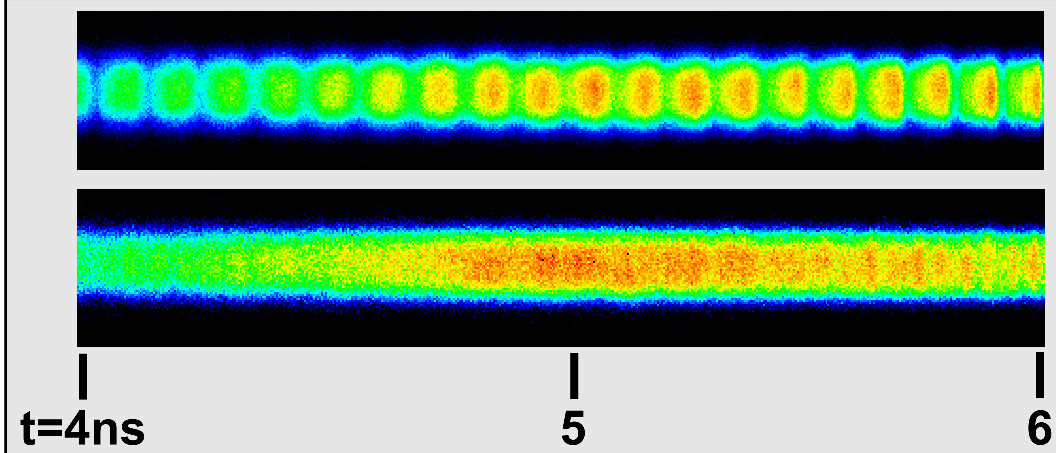
We shape the bandwidth to pre-compensate for non-uniform spectral gain through the system

Spectral shaping example



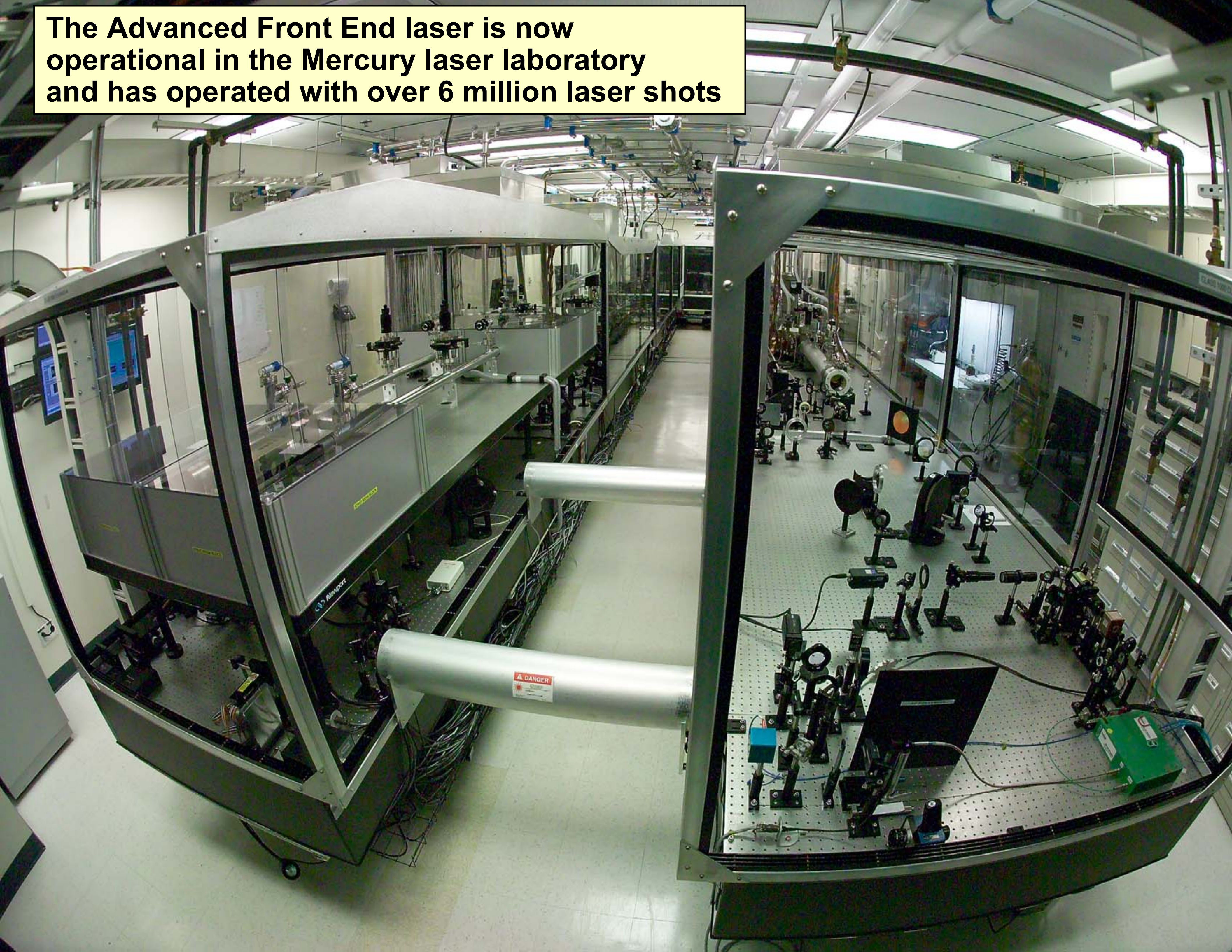
A Gaussian notch has been applied to the center of the spectrum

Reduction of FM-AM conversion



Streak camera images of the center of a 10nsec,150GHz pulse. The top image shows the amplitude fluctuations caused by FM-AM conversion. The bottom image has a spectral correction applied

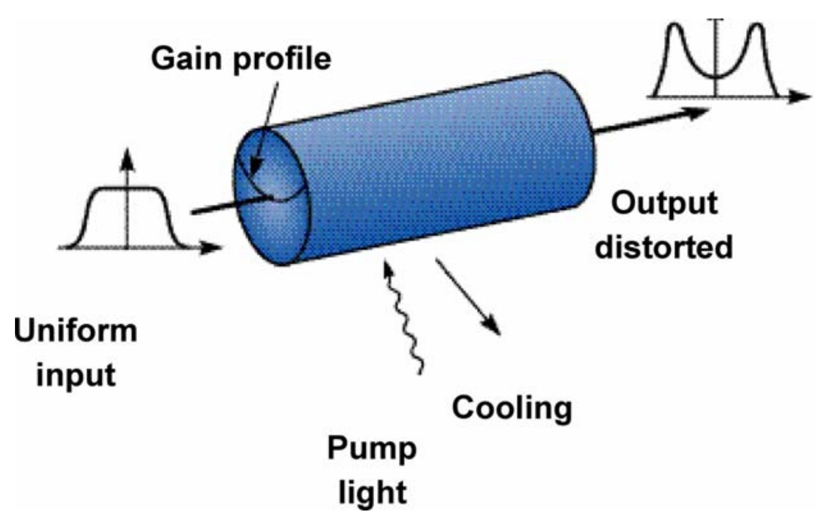
The Advanced Front End laser is now operational in the Mercury laser laboratory and has operated with over 6 million laser shots



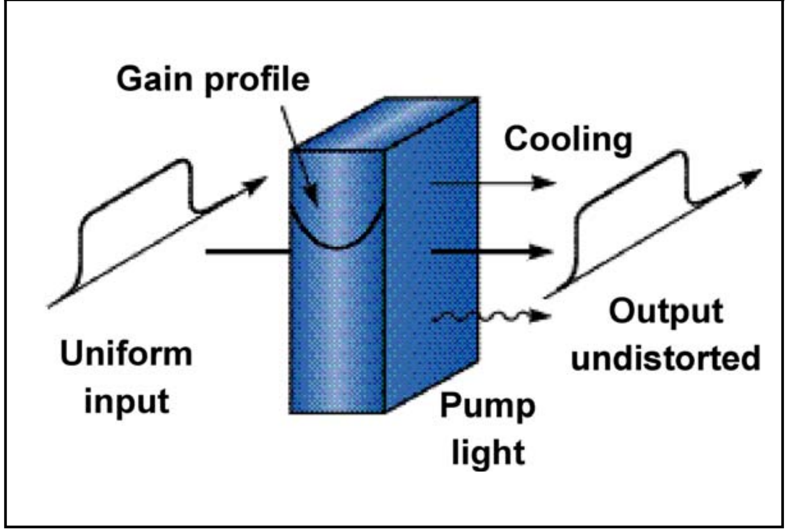
Gas Cooling Development

Face cooling with helium gas offers low scattering losses and thermal distortions

Transversely cooled rod laser



Longitudinally cooled rod laser



Scattered light: $\Delta n^2 \approx (G\, \Delta\rho/\rho)^2$

n = gas index

ρ = gas density

G = Gladstone-Dale coefficient

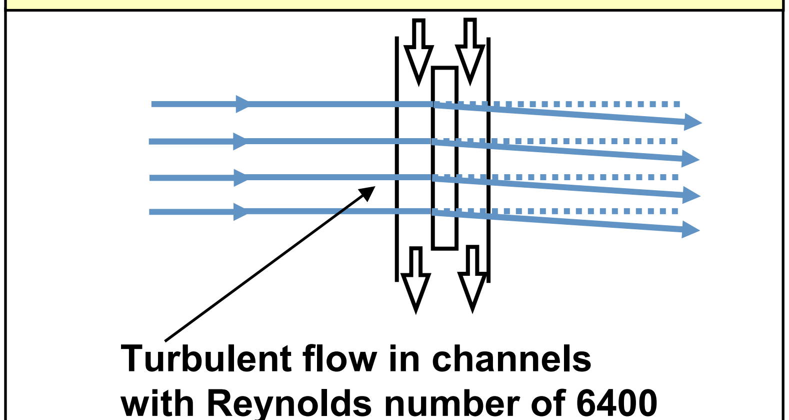
= 0.36×10^4 Helium

= 2.97×10^4 Nitrogen (7.4x larger)

= 2.92×10^4 Air (7.4x larger)

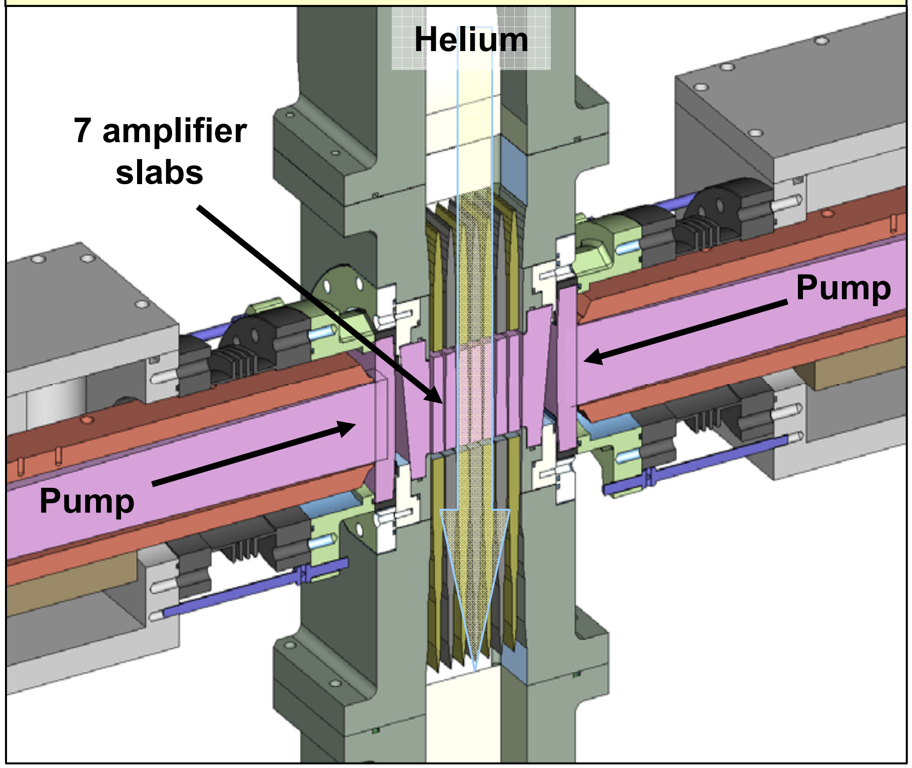
Helium scattering 66X lower than air!

Gas-cooling

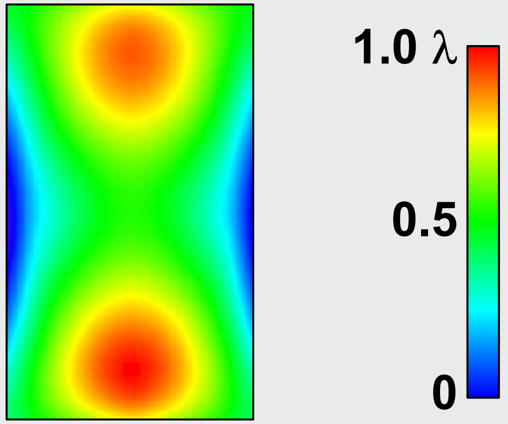


The thermally induced wavefront distortion has been experimentally benchmarked to a detailed thermal model

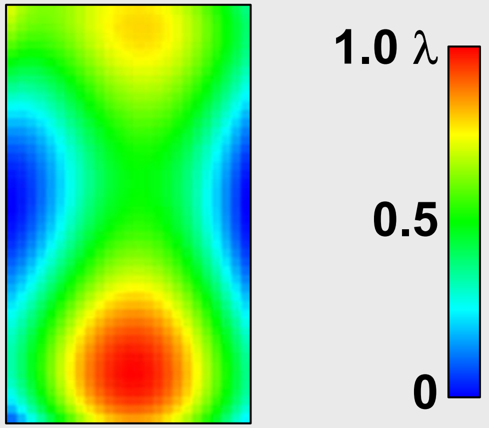
Mach 0.1 helium gas cooling



Thermal Model



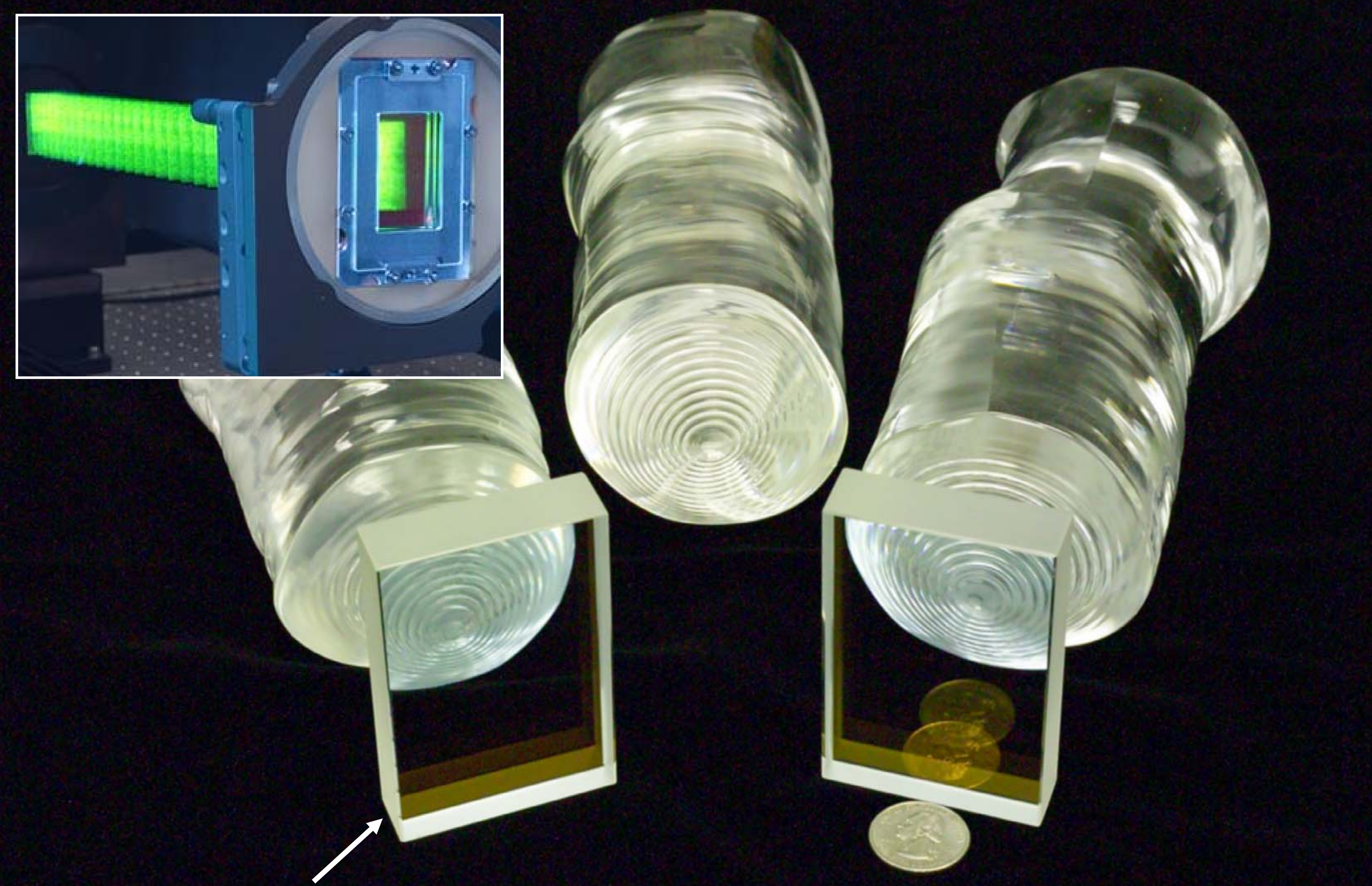
Experimental Data



The sub-sonic helium gas cooling technology is now qualified for IFE application

Frequency Conversion

Frequency conversion efficiency > 70% demonstrated on Mercury using YCOB, a thermally insensitive nonlinear material



Finished Mercury frequency converters

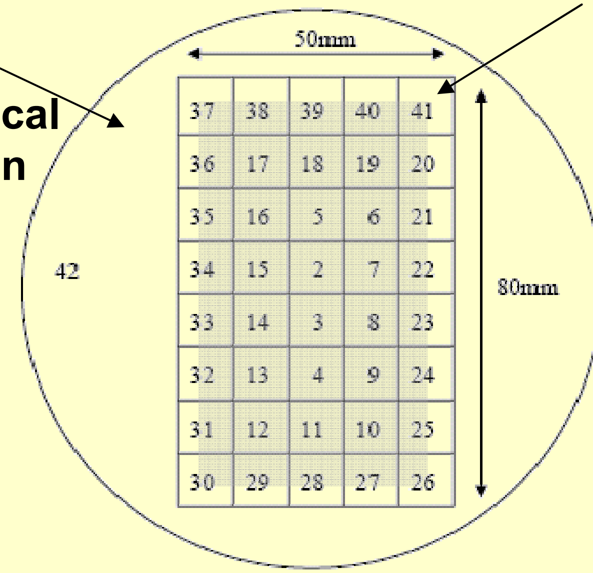
Crystal Photonics, Inc.

Adaptive Optics Development

The deformable mirror is a bimorph design which utilizes lithographically defined actuators to shape the mirror surface

Deformable mirror

The mirror has a "woofer-tweeter" design for optimum dynamic range.

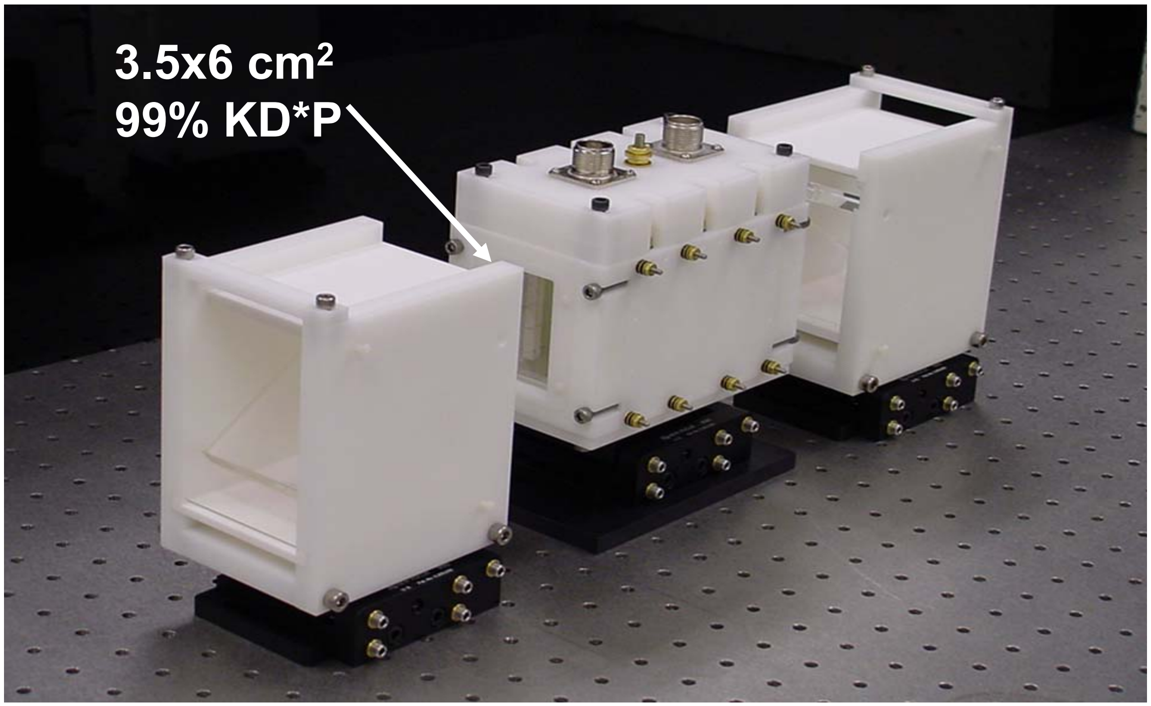


This qualified mirror technology can be mass produced at a low cost making it attractive for an IFE application

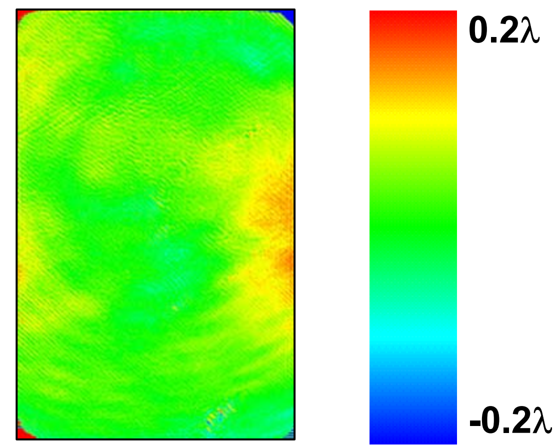
Adaptive Optic	Test result
Active aperture (mm^2)	45 x 75
Maximum stroke (woofer) (waves)	20
Maximum Stroke (tweeter) (waves)	6.0
Flatness (waves)	0.9
Damage Threshold (J/cm^2 @ 3.5 ns)	10.0

Pockels Cell Development

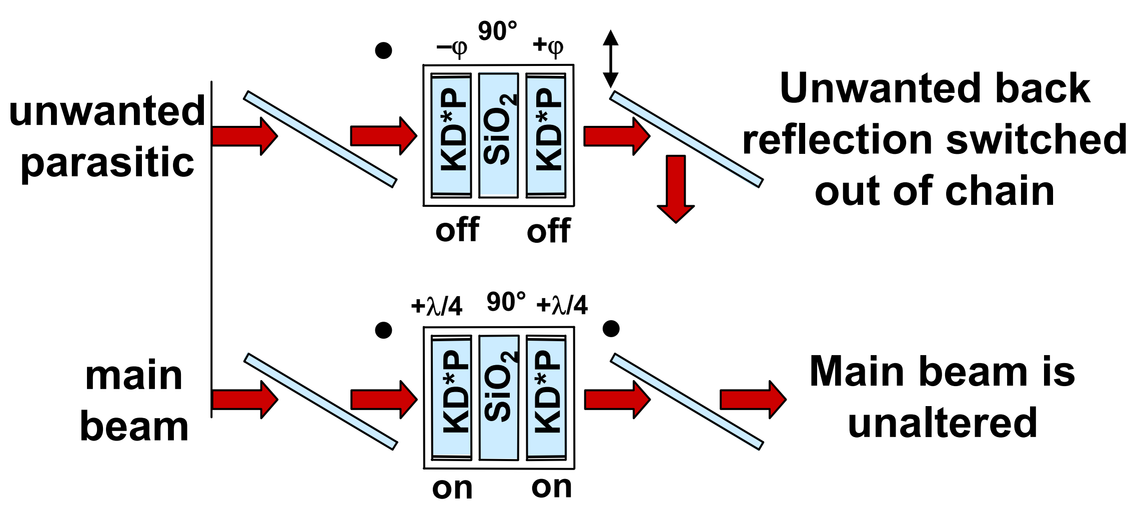
The 200 W Pockels cell developed for parasitic suppression in Mercury was awarded an R&D 100 Award



Transmitted wavefront distortion of the cell is low



How thermal birefringence compensation works

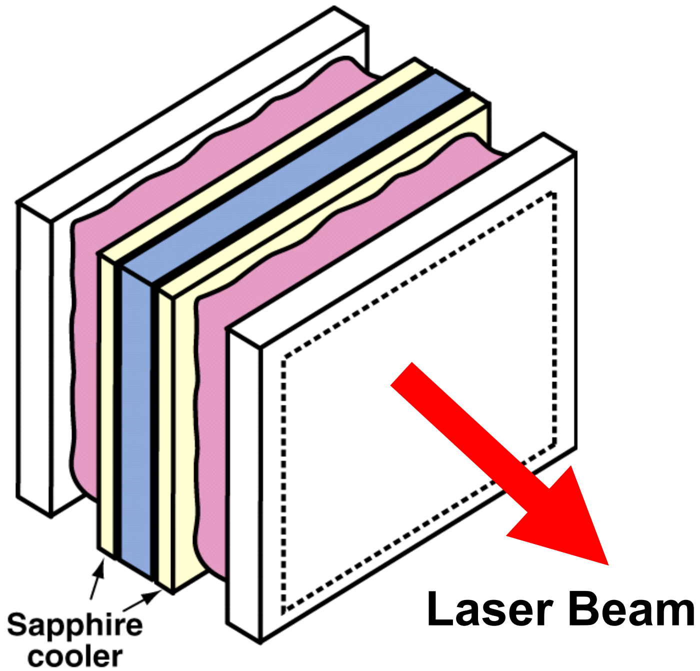


Pockels cell performance:

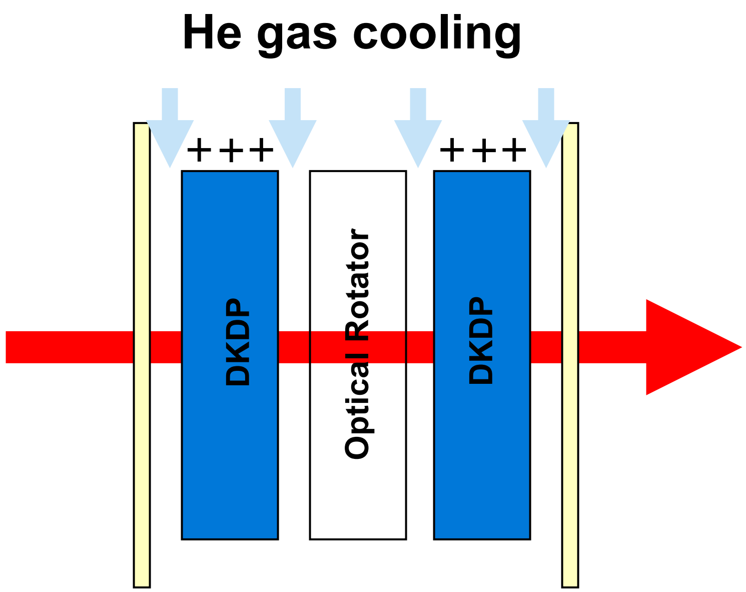
- Wavefront distortion: 0.15λ
- Average contrast: 200:1
- Rise time: 11 ns
- low EMI

High average power Plasma Electrode Pockels Cell (PEPC) and Transverse Electrode Pockels Cell (TEPC) concepts

Sapphire cooled PEPC



Transverse Electrode Birefringence Compensated Pockels Cell



Based on technologies developed on NIF and Mercury, an IFE scale Pockels cell is being designed

Integration

The front end controls provide automation, performance management, alignment, and diagnostic capability

Automation

- Startup and shutdown
- File-driven configurations
- Automated alignment

Performance management

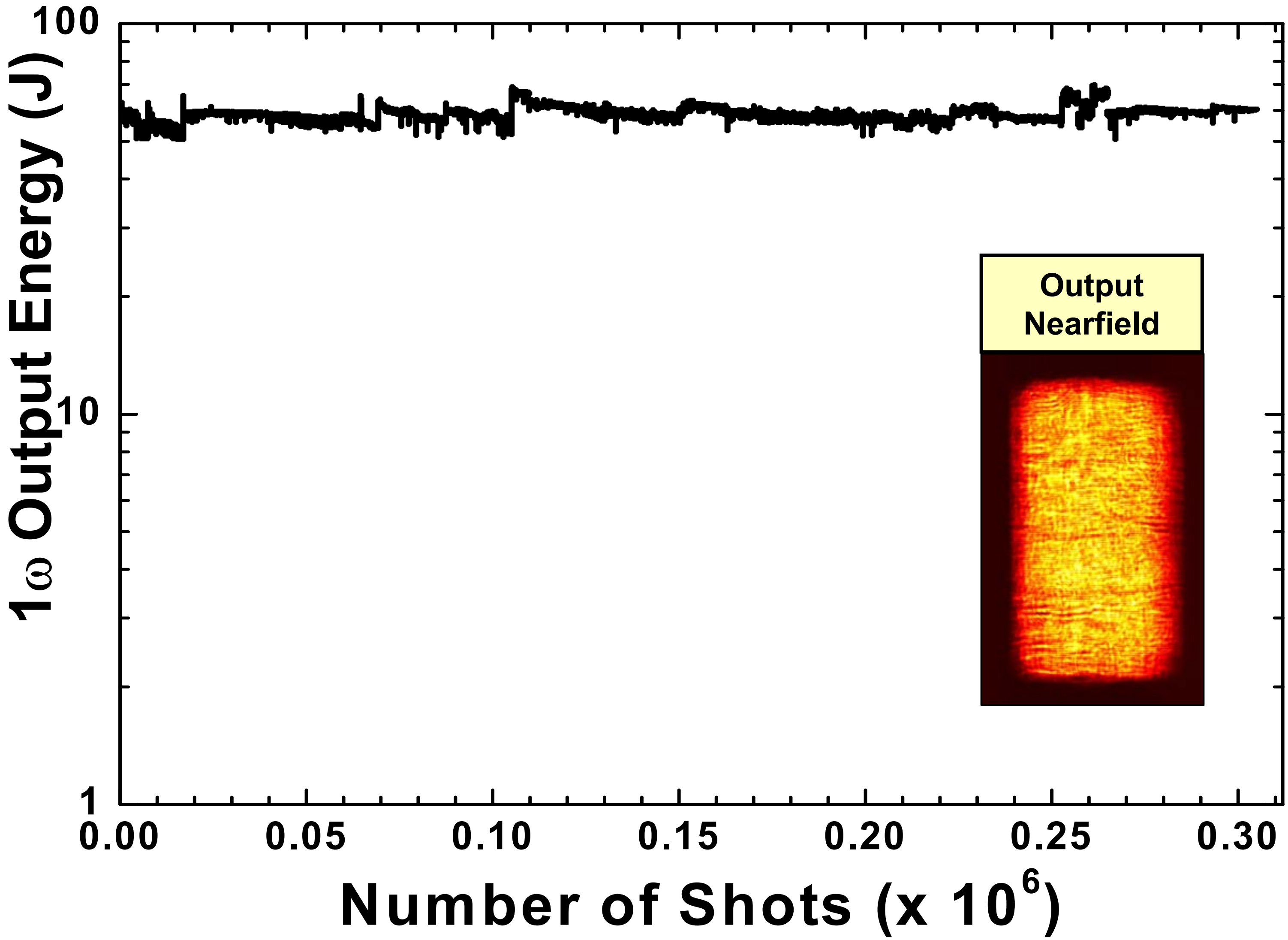
- Closed loop energy, wavelength, and temporal pulse stabilization

Diagnostics and trending

- Multiple channels of power, energy, spectra, and operating parameters archived for long term trending.

Mercury has operated above 50 Joules for over 0.3 million shots at 10 shots per second

Mercury shot histogram of consecutive 0.5 - 2 hr operations



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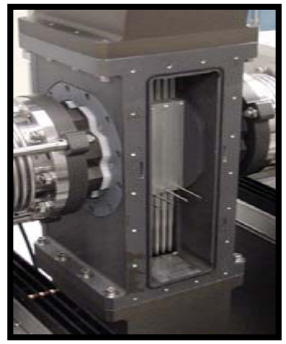
The Mercury laser employs many advanced technologies to achieve scalable, efficient, high-average-power operation

Diode Arrays

Gas Cooling

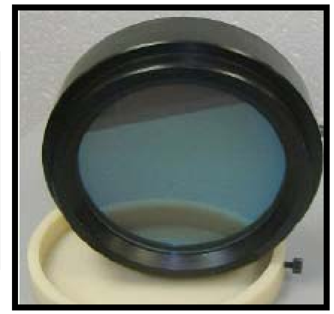


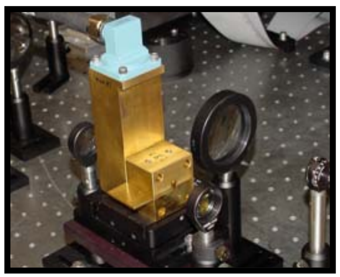
Front End

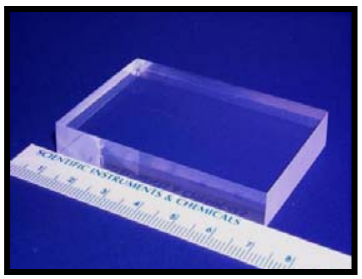
Gain Media

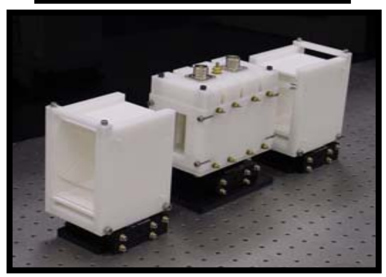
Pockels Cell

Adaptive Optic

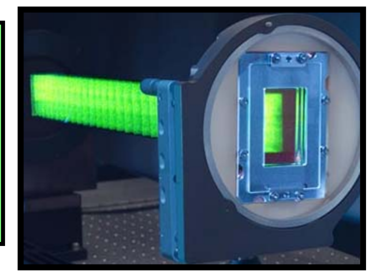








Frequency Conversion



Final Optic (TBD)

First Wall Test (TBD)

- **Poster "High Average Power Petawatt Laser Pumped by the Mercury Laser for Fusion Materials Engineering" on Tuesday**

Petawatt / Mercury Team:

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Andy Bayramian
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Industrial Collaborators:

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Directed Energy, Inc.
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Northrop-Grumman
Onyx Optics
PHASICS
Night N (opt) Ltd.
Crystal Photonics
Quality Thin Films
Schott Glass Technologies
SESO
Spica
Zygo

PHOTON

SCIENCE & APPLICATIONS