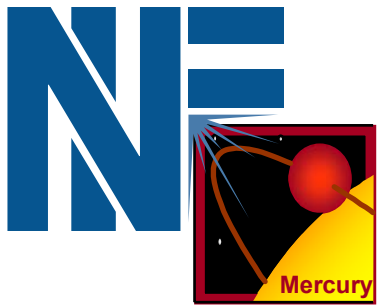
The Mercury Laser - Progress Update



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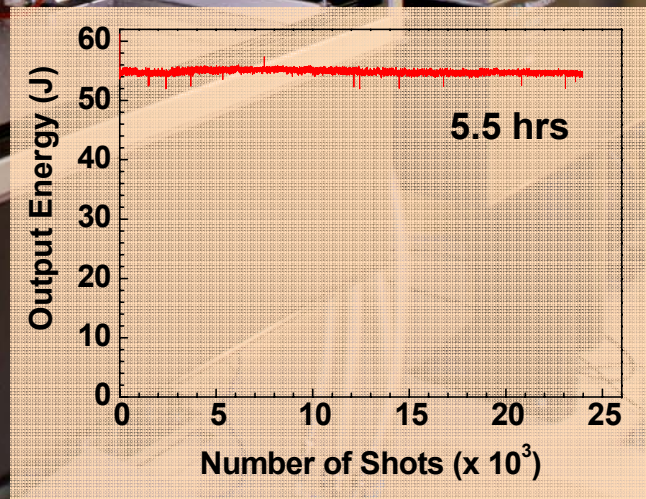
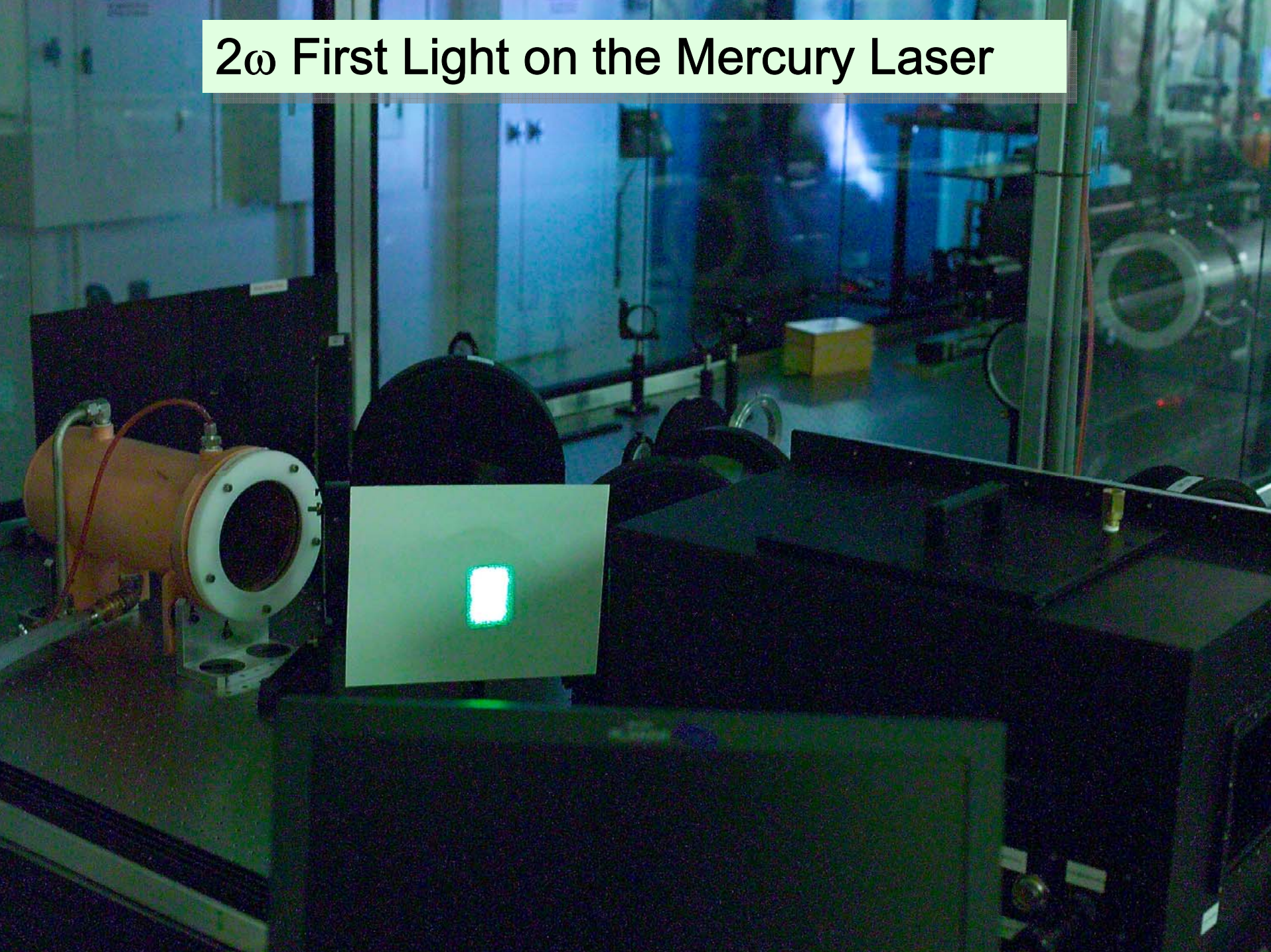
March 3 & 4 2005

This work was performed under the auspices of the U. S. Department of Energy by the University of California, Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48.

Mercury Laser
55J at 3.3 Hz for >10^3 shots



2ω First Light on the Mercury Laser



Outline

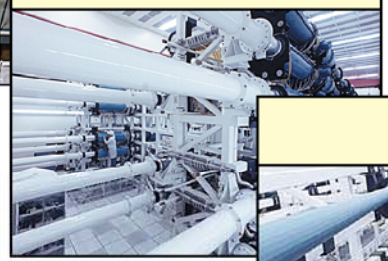
- **Project Overview**
  - Mercury Laser performance goals and status
- **Component and system performance**
  - Pump diode arrays
  - Crystalline gain media
  - Gas cooled amplifiers
  - 1 μm operation
  - Frequency conversion
- **Next Generation Design Considerations**
  - Laser architecture building blocks

LLNL has had a long history of building high energy, high peak power laser facilities

Janus

100J IR

Shiva



10KJ IR

Nova

30KJ UV

NIF

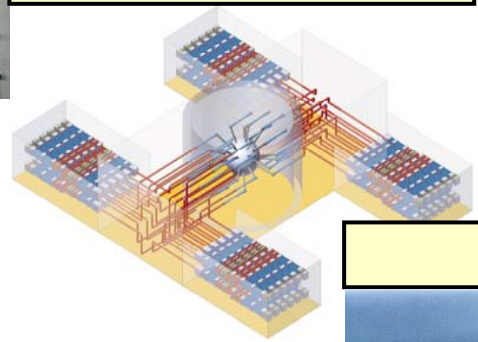
1.8MJ UV

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

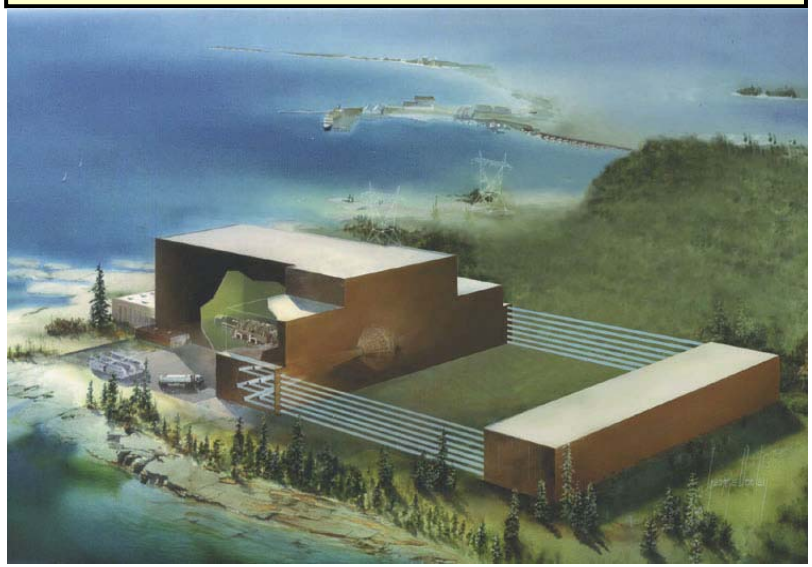
Mercury 100 J

10 Hz Bundle 10 KJ

ETF 2 MJ



IFE

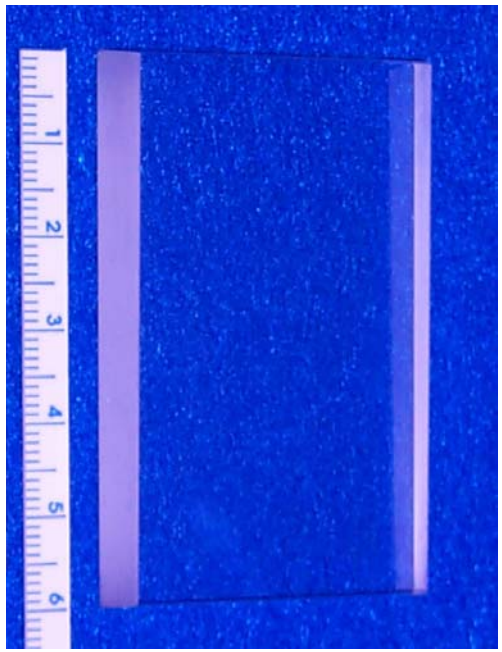


Mercury Goals:

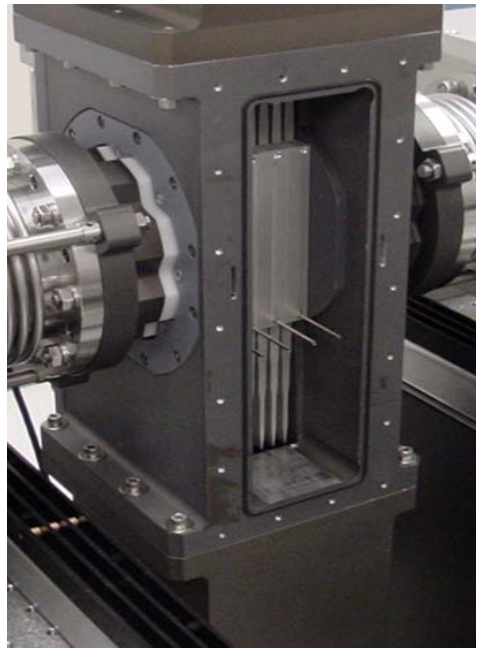
Energy: 100 J
Efficiency: 10%
Repetition rate: 10 Hz
Pulse length: 3-10 ns
Wavelength: 0.53/0.35 μm
Bandwidth: 150 GHz 1ω
Beam quality: 5 xDL

The Mercury Laser amplifier technologies

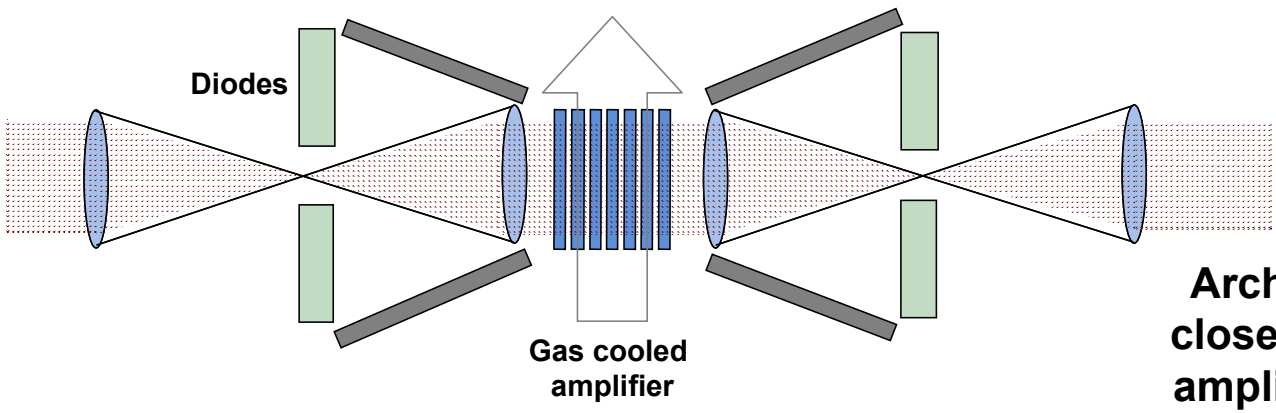
Diode pump arrays



Yb-crystalline amplifiers



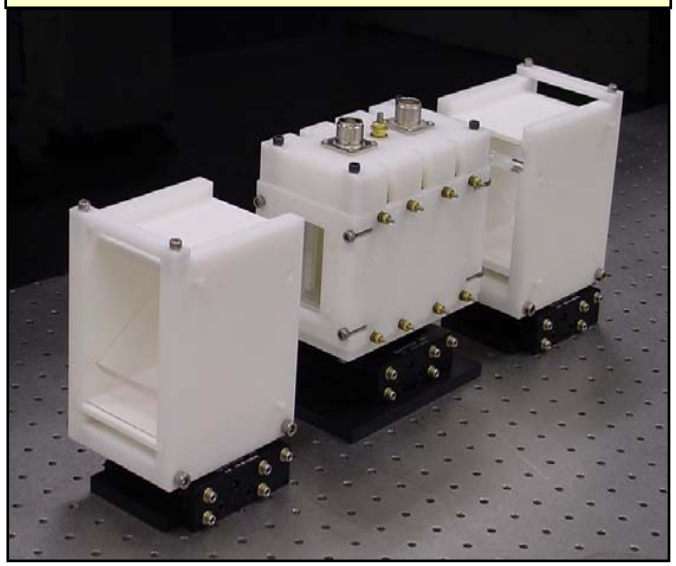
Helium gas cooling



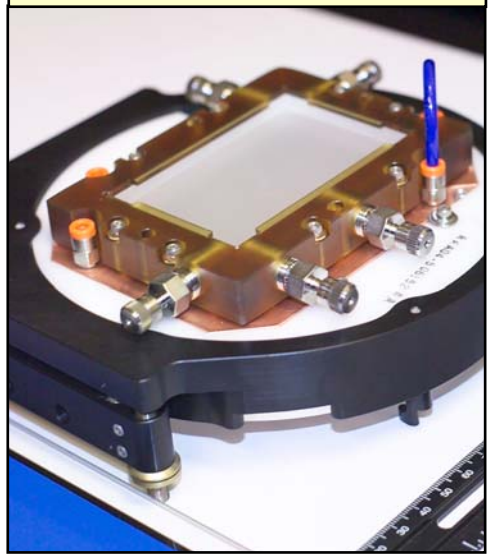
Architecture: closely-spaced amplifier slabs

We are deploying advanced beam control technologies

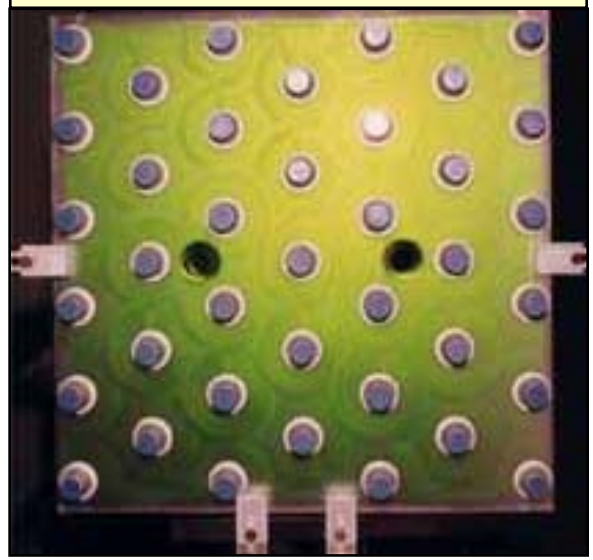
Temporal



Wavelength



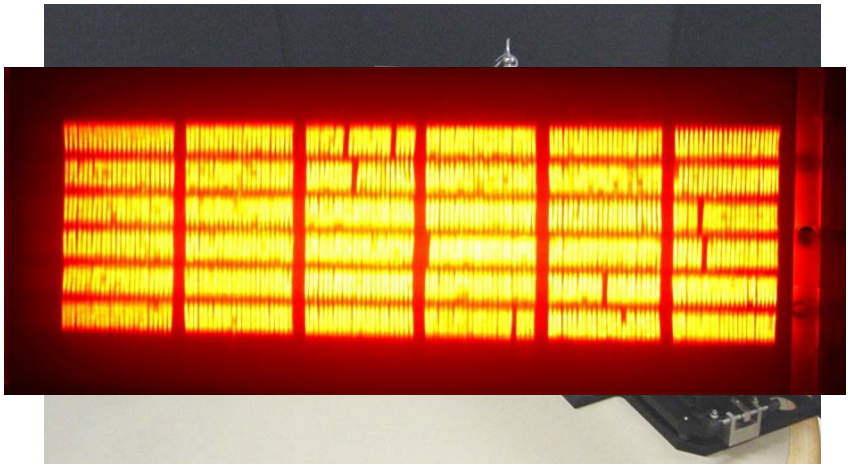
Wavefront



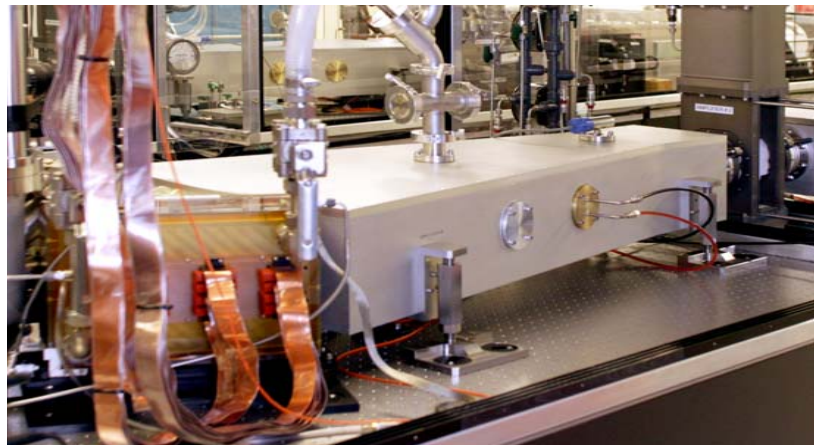
These components are being commissioned this year for frequency conversion to 2ω and improved beam quality

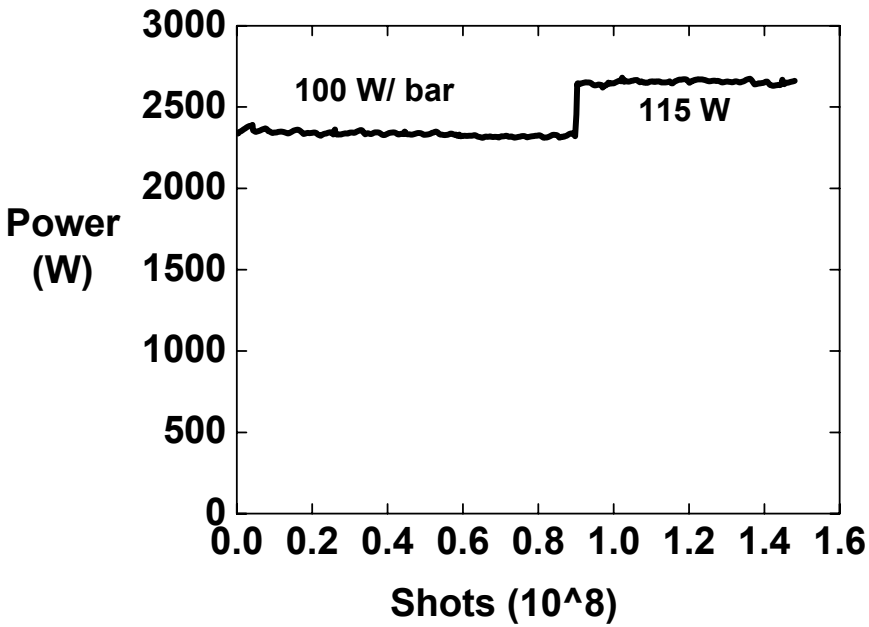
Diode tiles and arrays have incurred up to 10^8 shots with no intrinsic failures

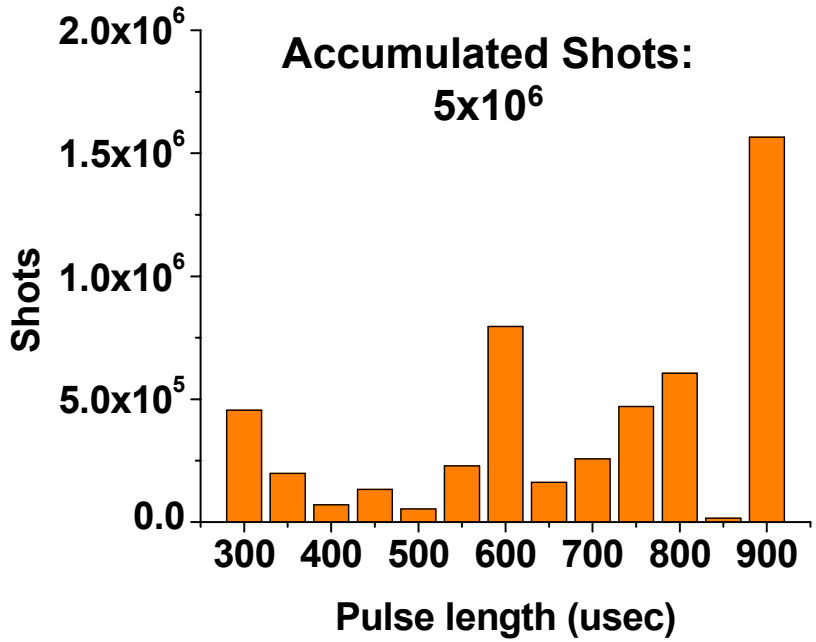
Offline tile tests: 1.5 x 10^8 shots



Mercury diode arrays: 5 x 10^6 shots







Each amplifier is pumped by 320 kW of peak diode power

Diode tile attributes	Goal	Performance	
Power	100 W / bar	120 W / bar	✓
Reliability	2 x 10^8 shots at 100 W / bar	1.4 x 1 0^8 shots at 115 W / bar	✓
Power droop over 1 msec	15%	4.3%	✓
Linewidth	5 nm	2.3 nm	✓
Integrated linewidth over 1 msec	8.5 nm	4.1 nm	✓
Divergence	18 x 180 mrad	15 x 140 mrad	✓
Efficiency	50%	45%	✓

A commercial company, is producing diode tiles based on LLNL technology

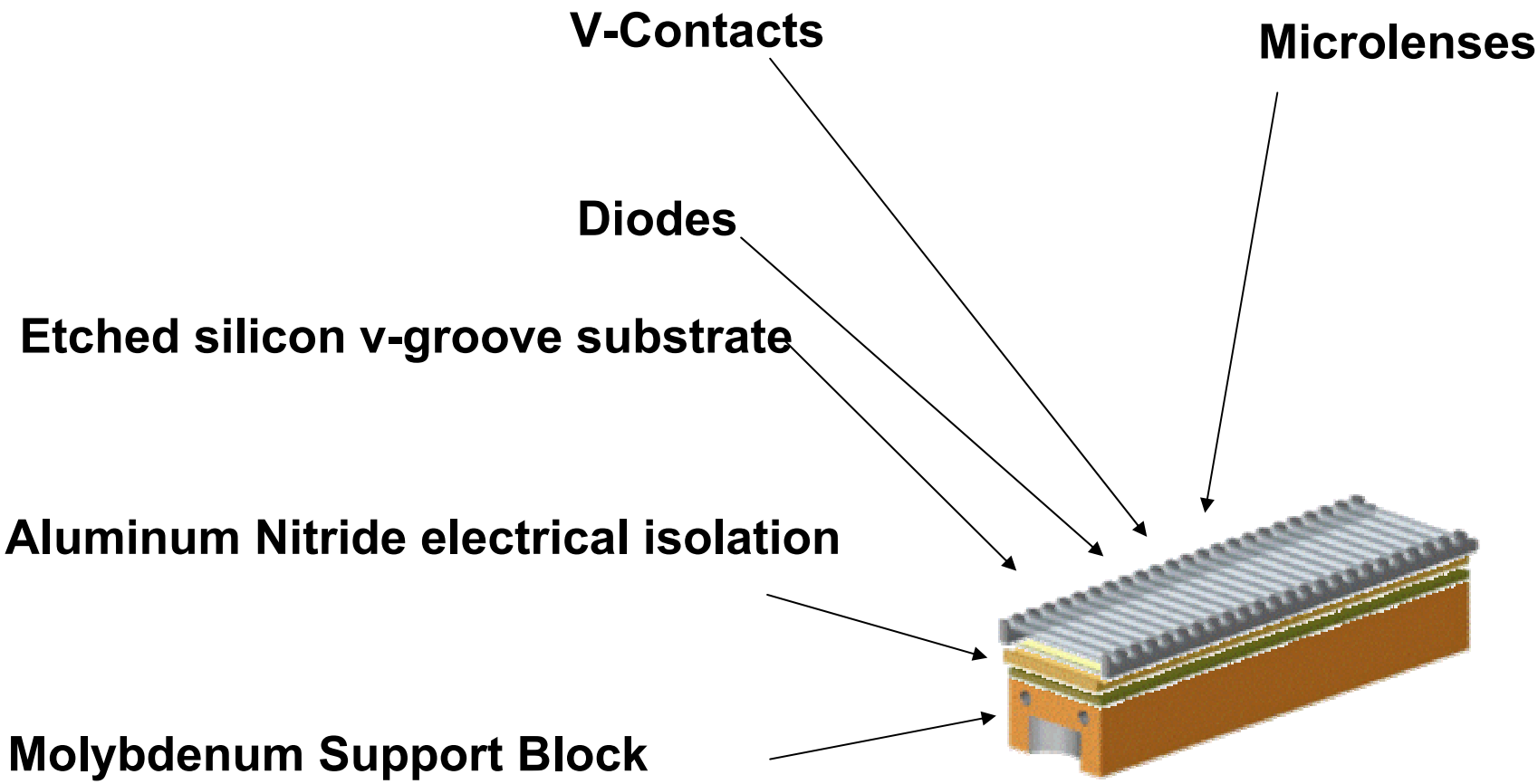
Two tiles will be delivered next month for testing

Test Station

Task status:

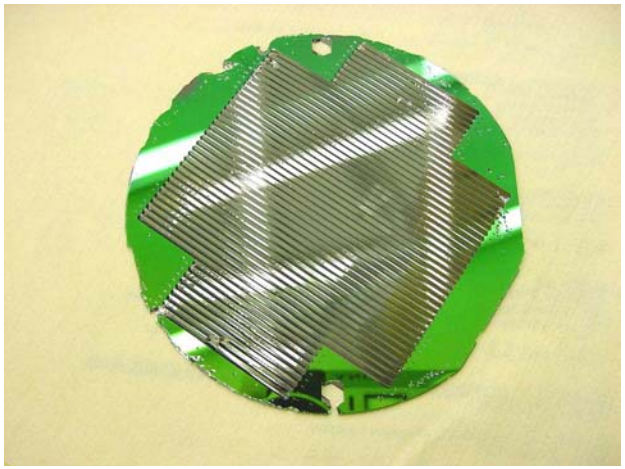
LLNL technology transfer	100%
Tooling fabrication	100%
Test station and characterization	100%
Vendor for Si submount	100%
Inspection of components	80%

The diode tile requires several production steps

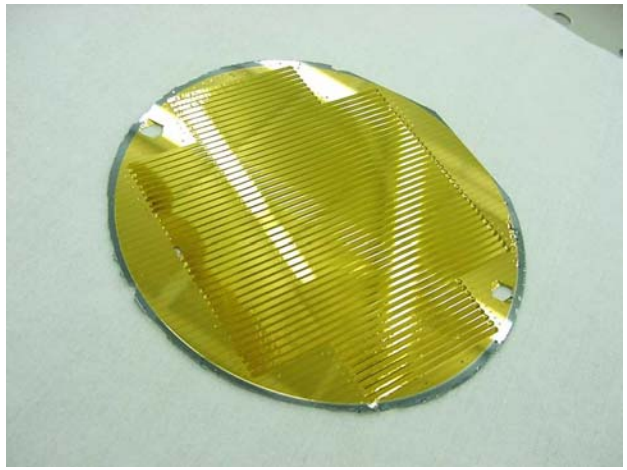


Production of diode tile components has begun

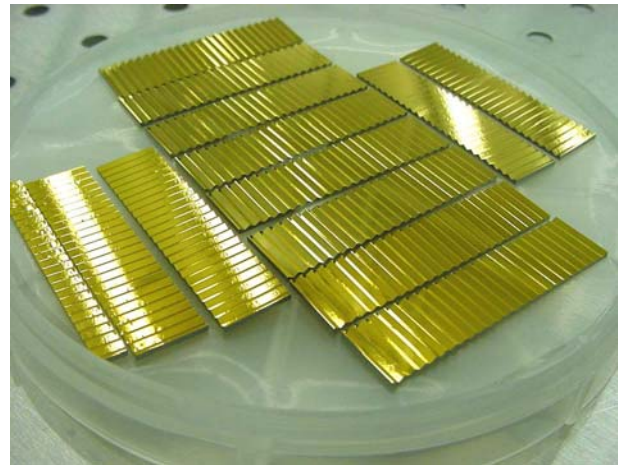
KOH Etching



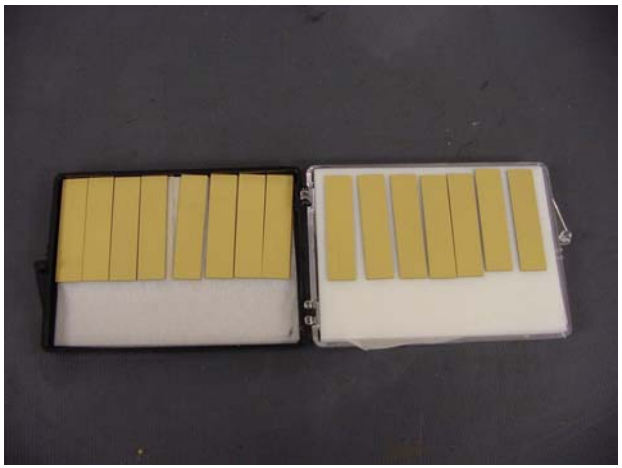
Metalization



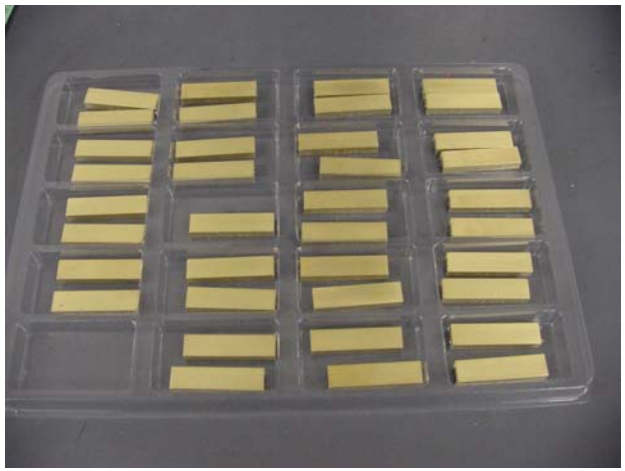
Dicing



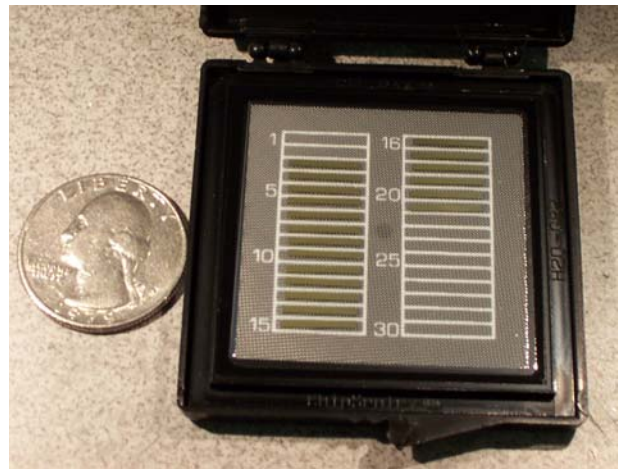
Aluminum Nitride



Molybdenum Heatsinks



Diode bars



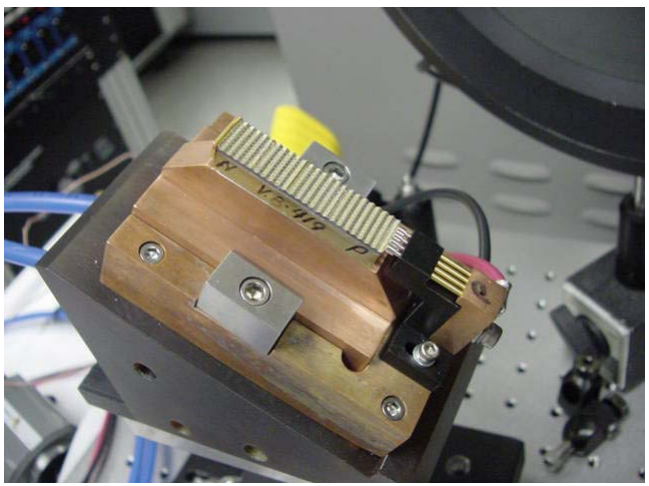
Diode tiles are being assembled and tested

Tiles without bars

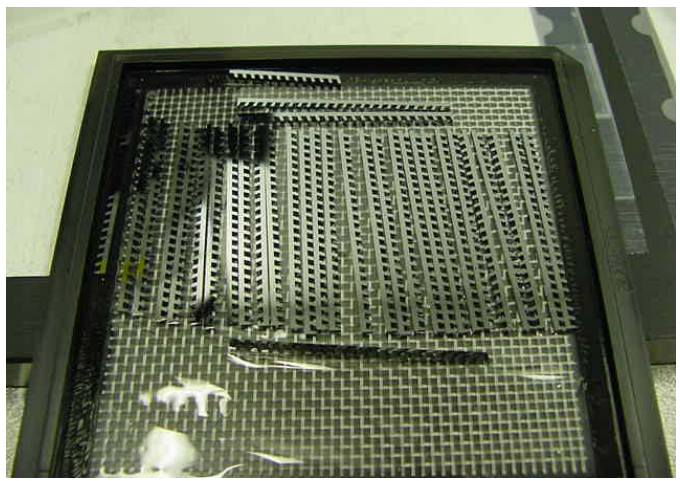
N-contact sheets

Tiles with bars

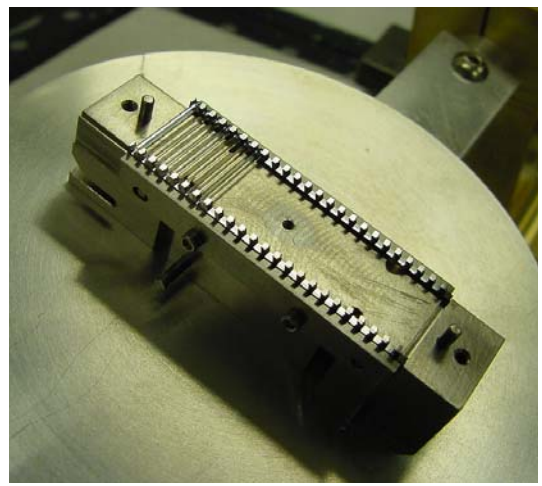
Test Fixture



Lens Frames

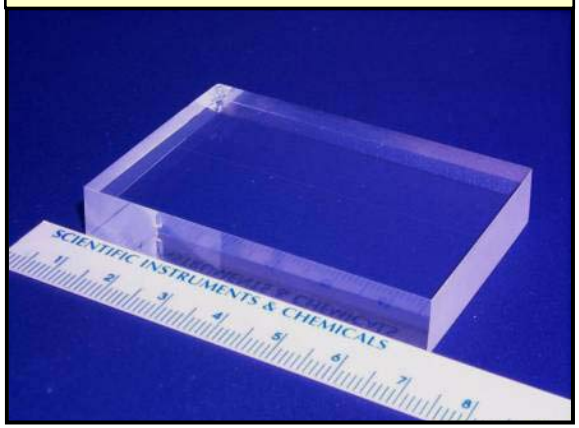


Lens Assembly

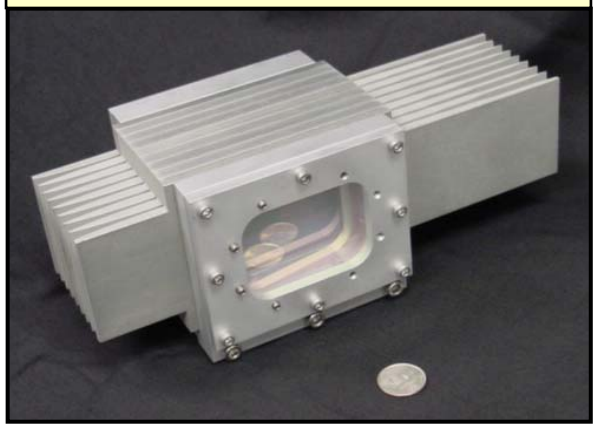


The amplifiers are now populated with 12 of 14 slabs with an additional 14 in the queue

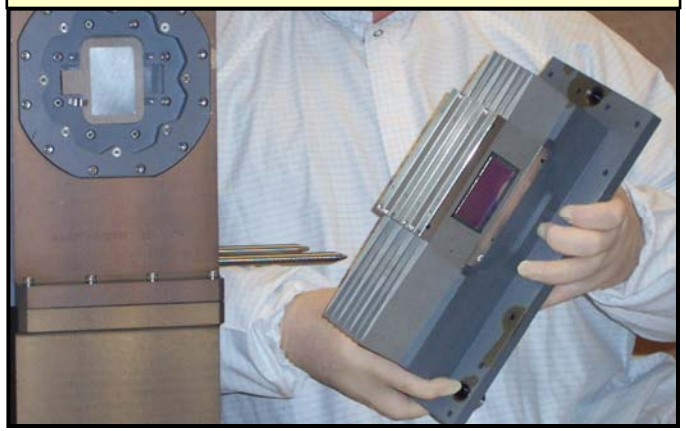
4x6 cm^2 Yb:S-FAP slab



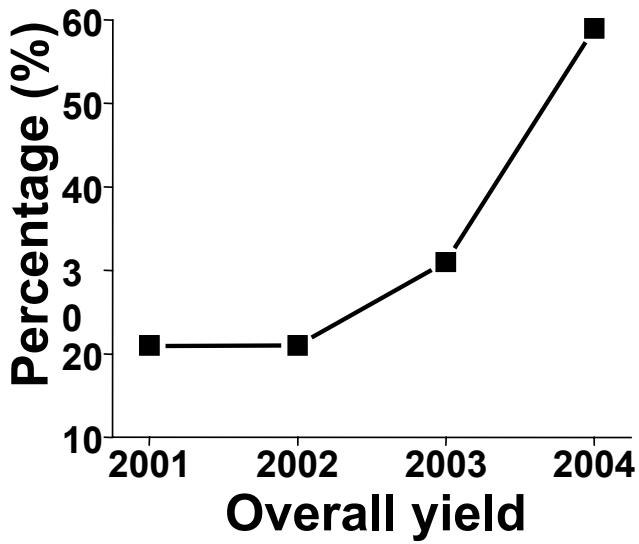
7 vane cooling elements



Amplifier Assembly

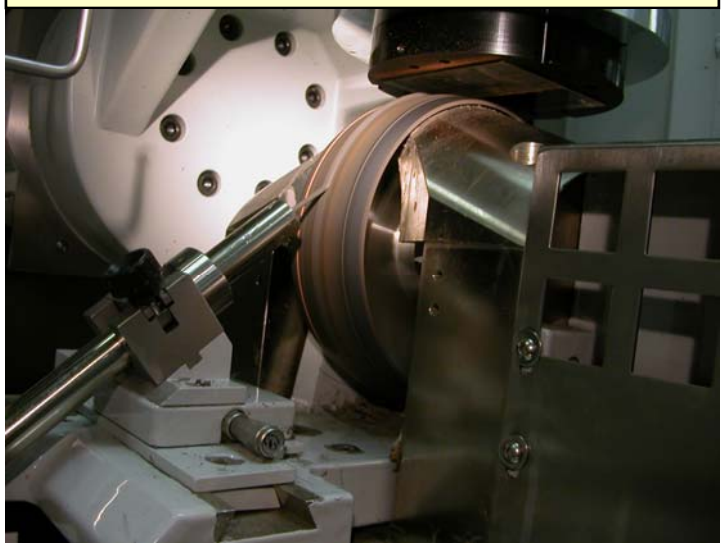


Production improvements and availability of large boules have increased yield allowing full complement of spares

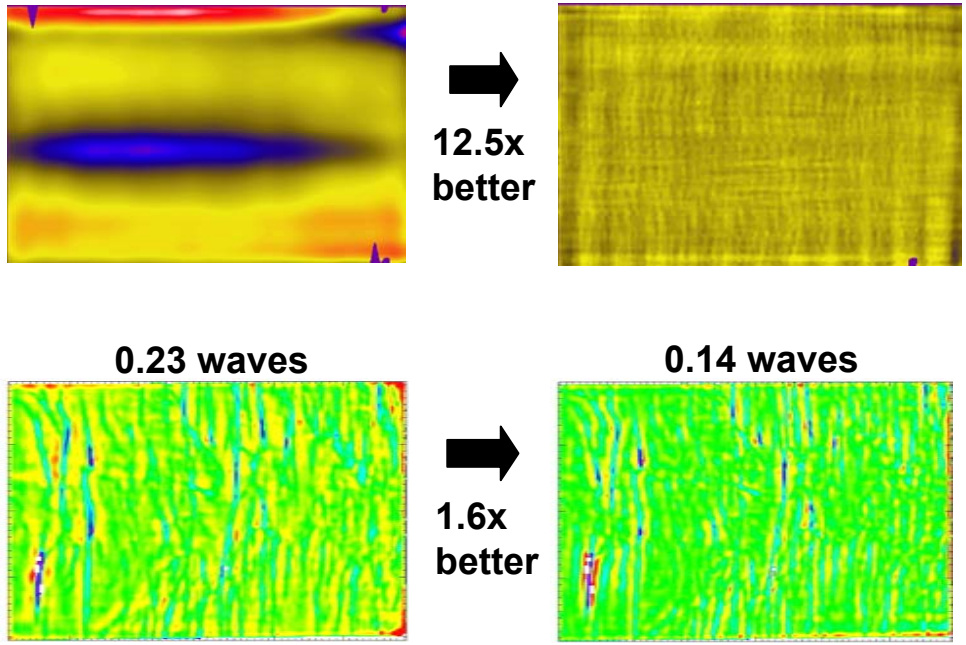


The Magnetorheological Finishing (MRF) machine is being used to improve the wavefront of Yb:S-FAP slabs

MRF machine

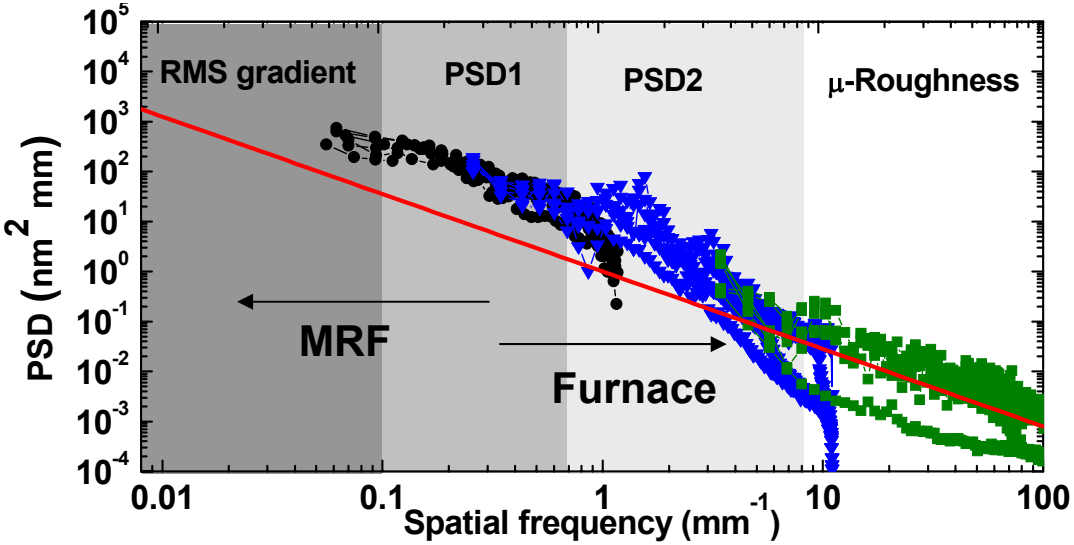


	Before		*After MRF*
Small boules	0.95 waves	12.5x better	0.076 waves
Large	0.23 waves	1.6x better	0.14 waves



Small scale waviness in full size slabs are due to grain boundaries and we are developing methods to eliminate them

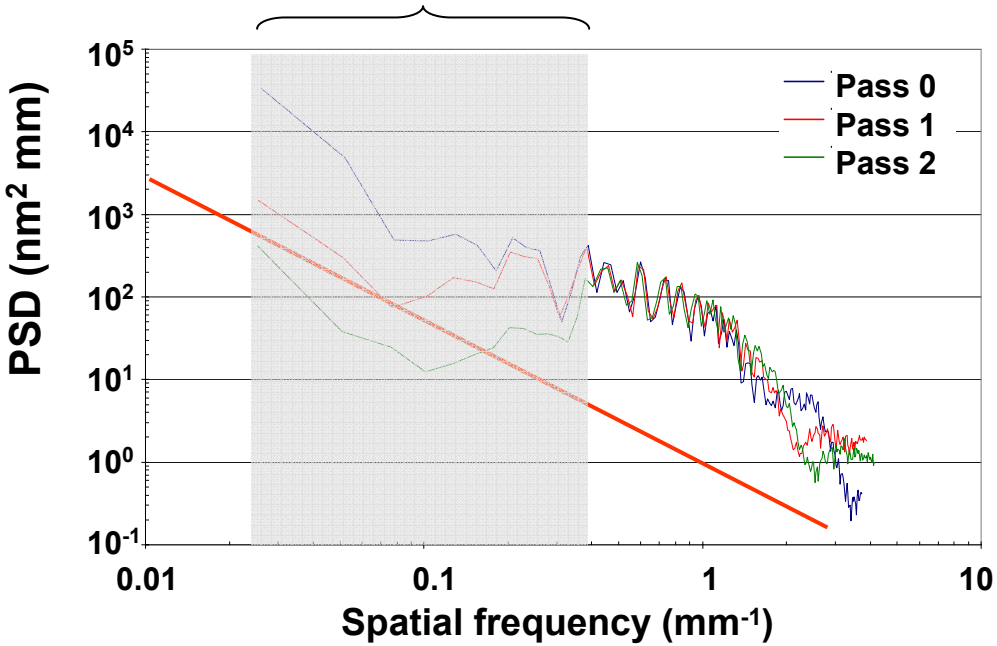
Power spectral density (PSD) plots quantify the finishing improvements



PSD is divided into regions that influence the beam properties

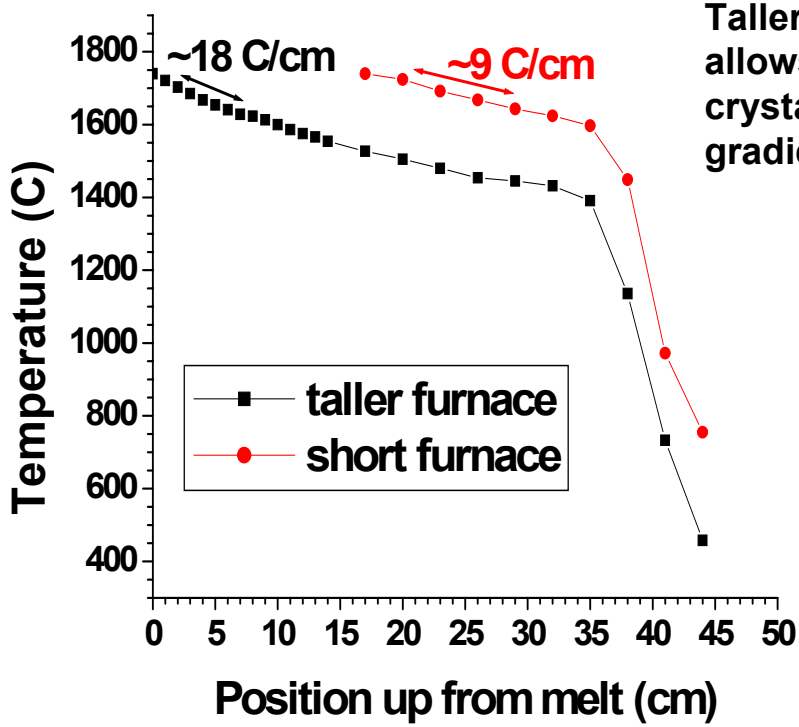
MRF improves the wavefront for frequencies > 3mm

Region of improvement



We are now concentrating on improving the overall optical quality through simple furnace modifications

CZ Station 3

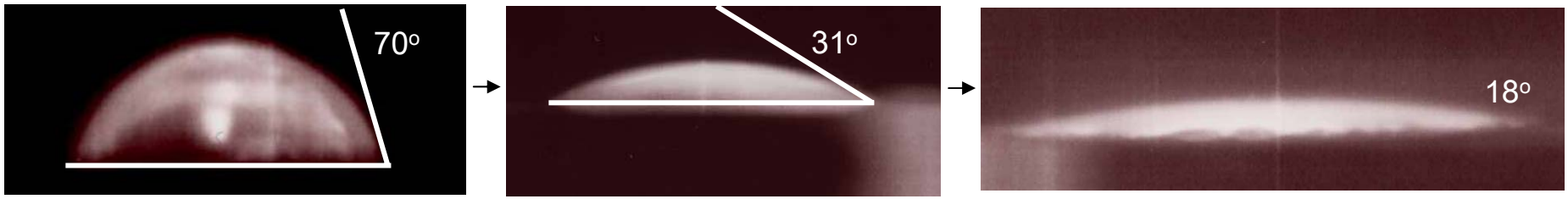


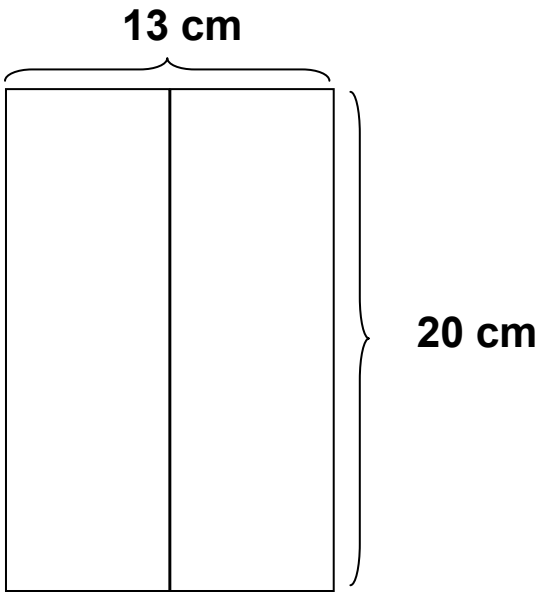
Taller furnace allows longer crystal and better gradients

- Challenge: Grain boundary defects
  - Formed when defect sites migrate together to relieve thermal stresses
- How might we mitigate them?
  - "Pin" defect sites with a larger cation to prevent migration
  - Prevent cool down induced thermal stresses

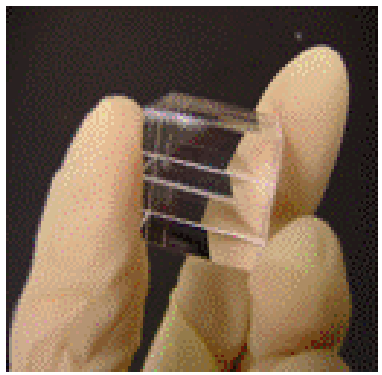
For an IFE scale laser, we are testing room temperature glue bonding

Ethanol clean → **+ Schott cleaning procedure** → **+ Plasma-asher**





Schott cleaning with "plasma-ashing" reduces surface contact angle for better bonding

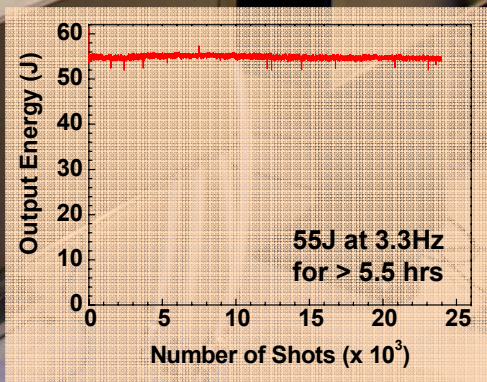


We plan to "stitch" two (or more) 7x20 cm slabs together to form a multi-kilojoule aperture for an IFE laser

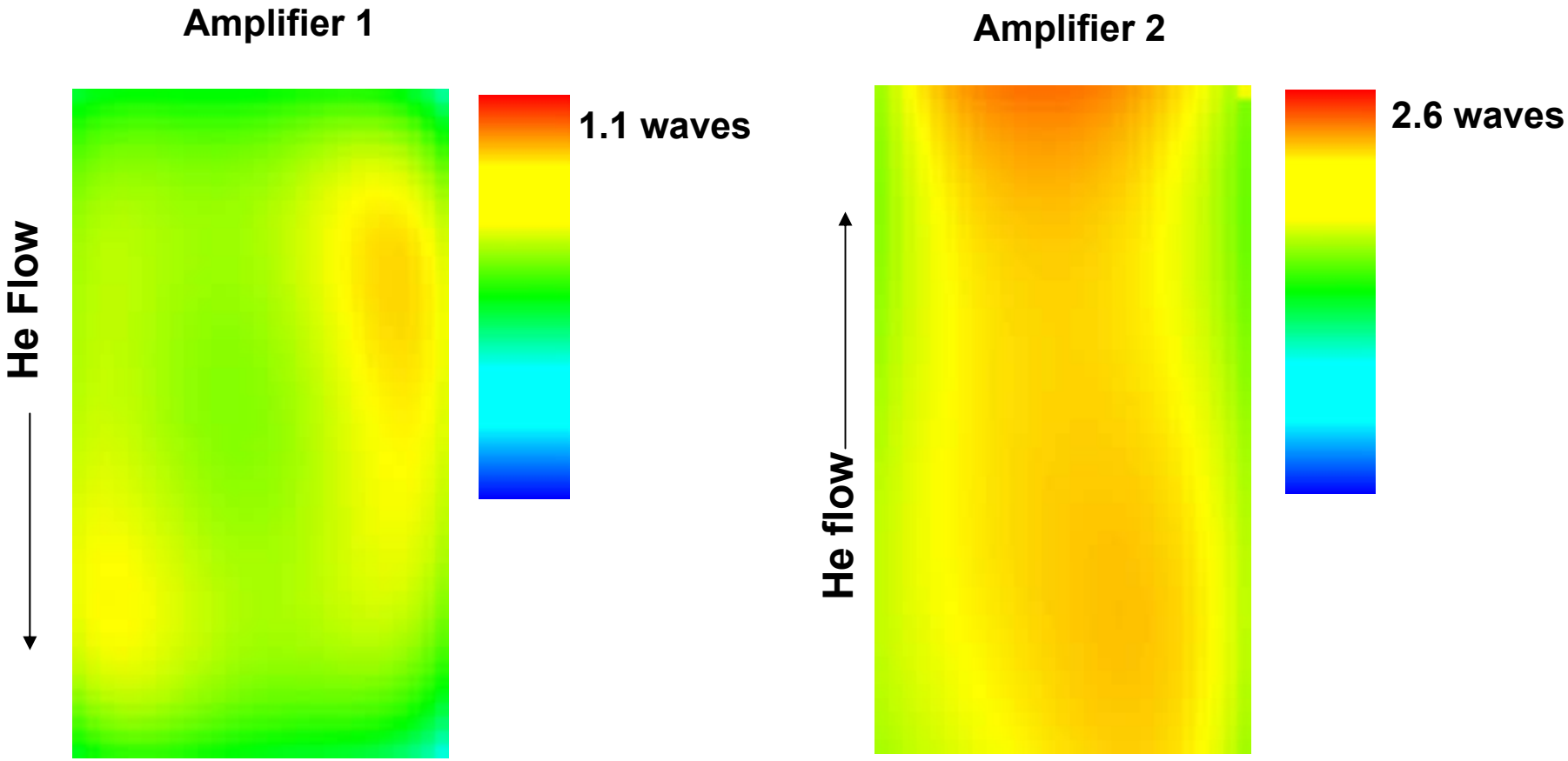
The Mercury Laser

Gas Cooled Amplifier with Crystalline Slabs

80 kW Diode Array

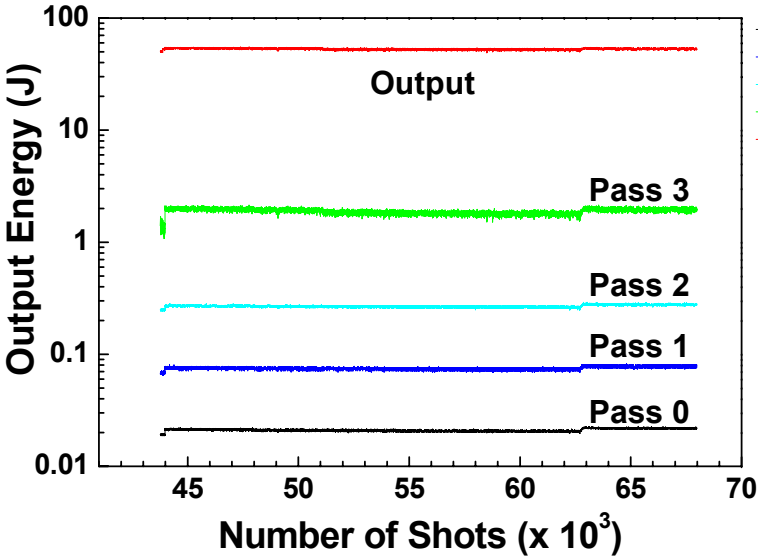


We have deployed a new rep-rated diagnostic to actively record the wavefront of the beam

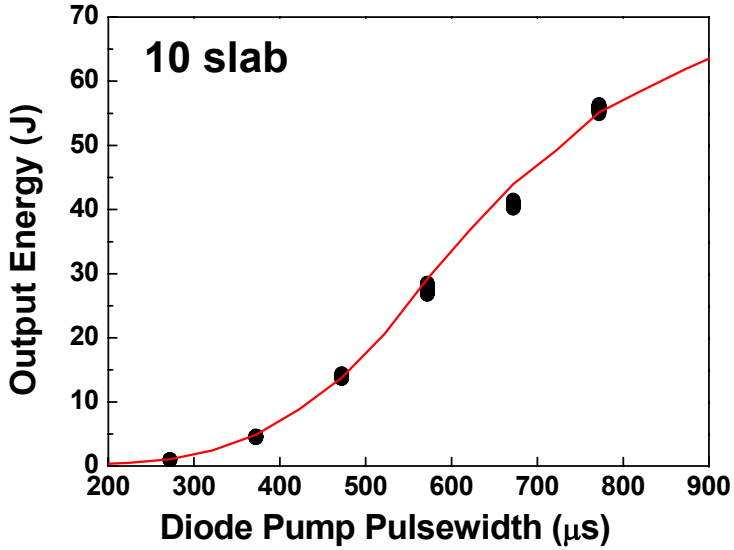


Mercury was operated for 55 J at 3.3 Hz for > 5.5 hrs with no optical damage with 10 slabs

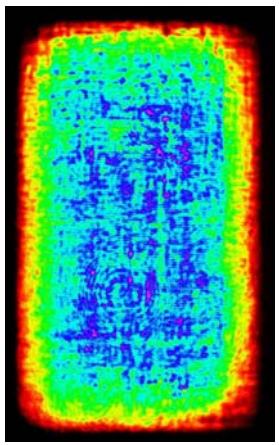
Average power

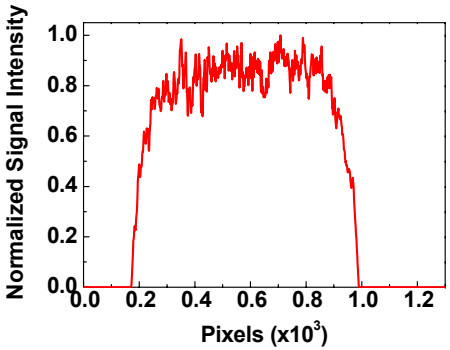


Single shot energetics

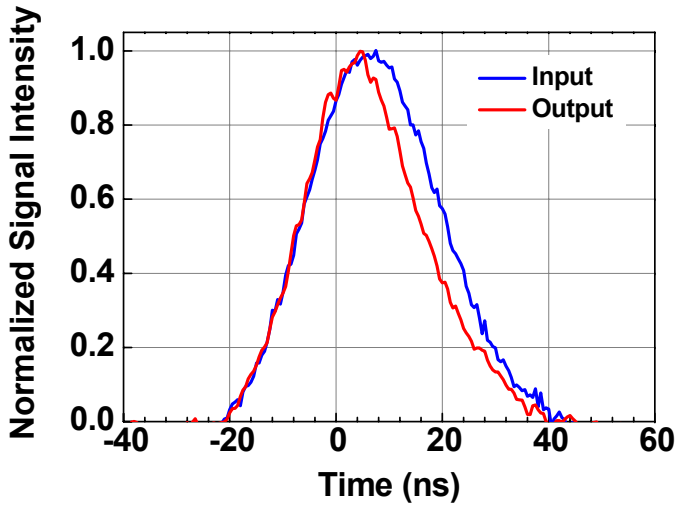


Nearfield image



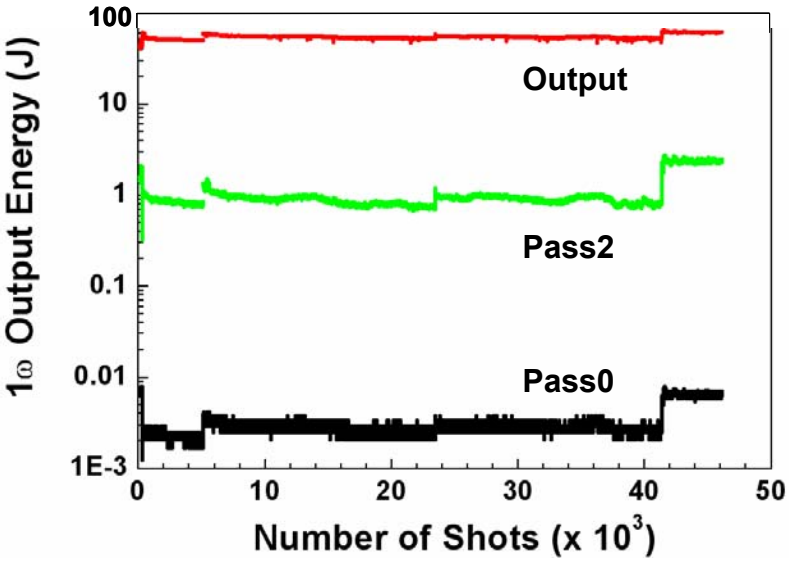


Temporal Pulse

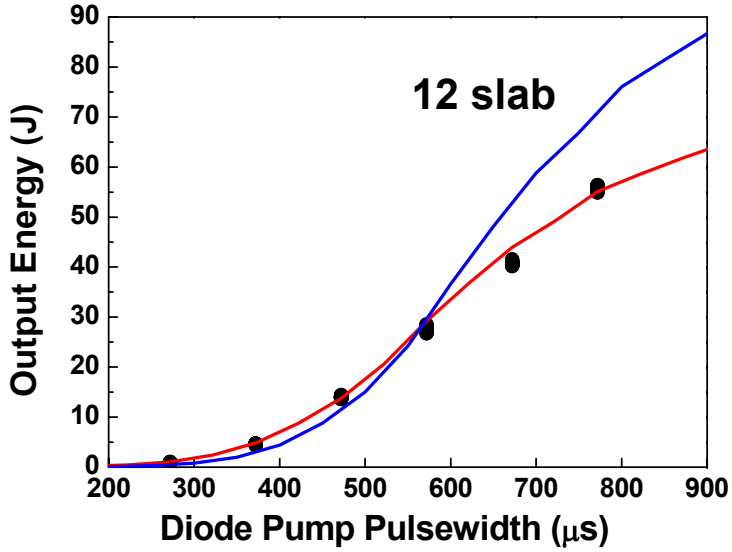


Mercury was operated for 55J at 5 Hz for > 2.5 hrs with no optical damage with 12 slabs

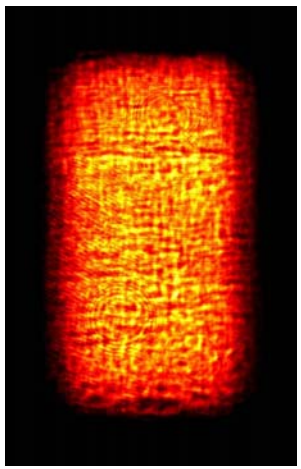
Average power



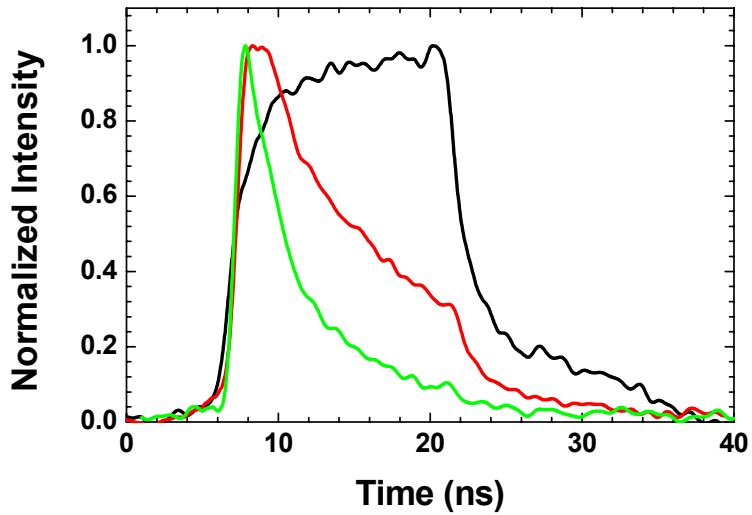
Single shot energetics



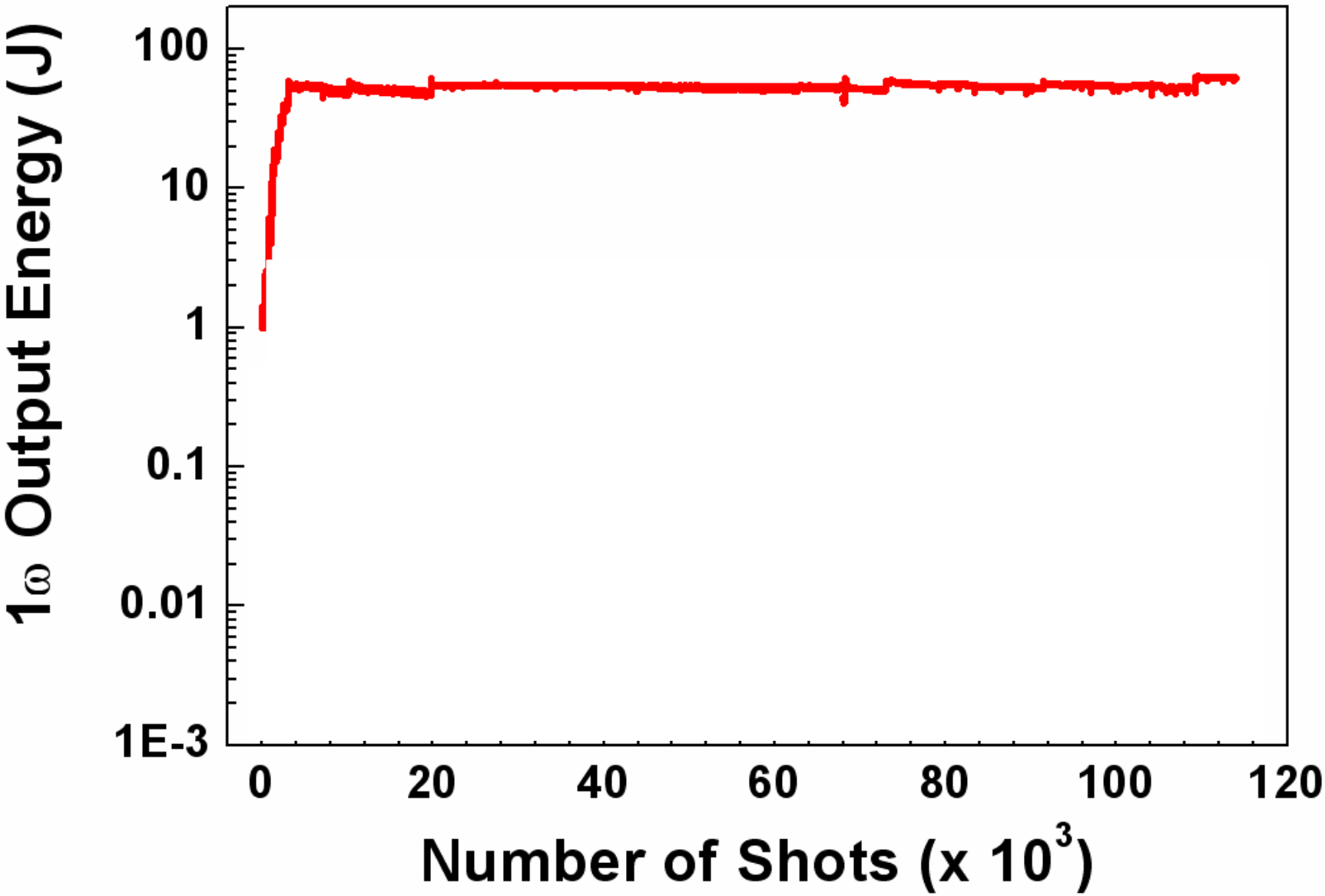
Nearfield image



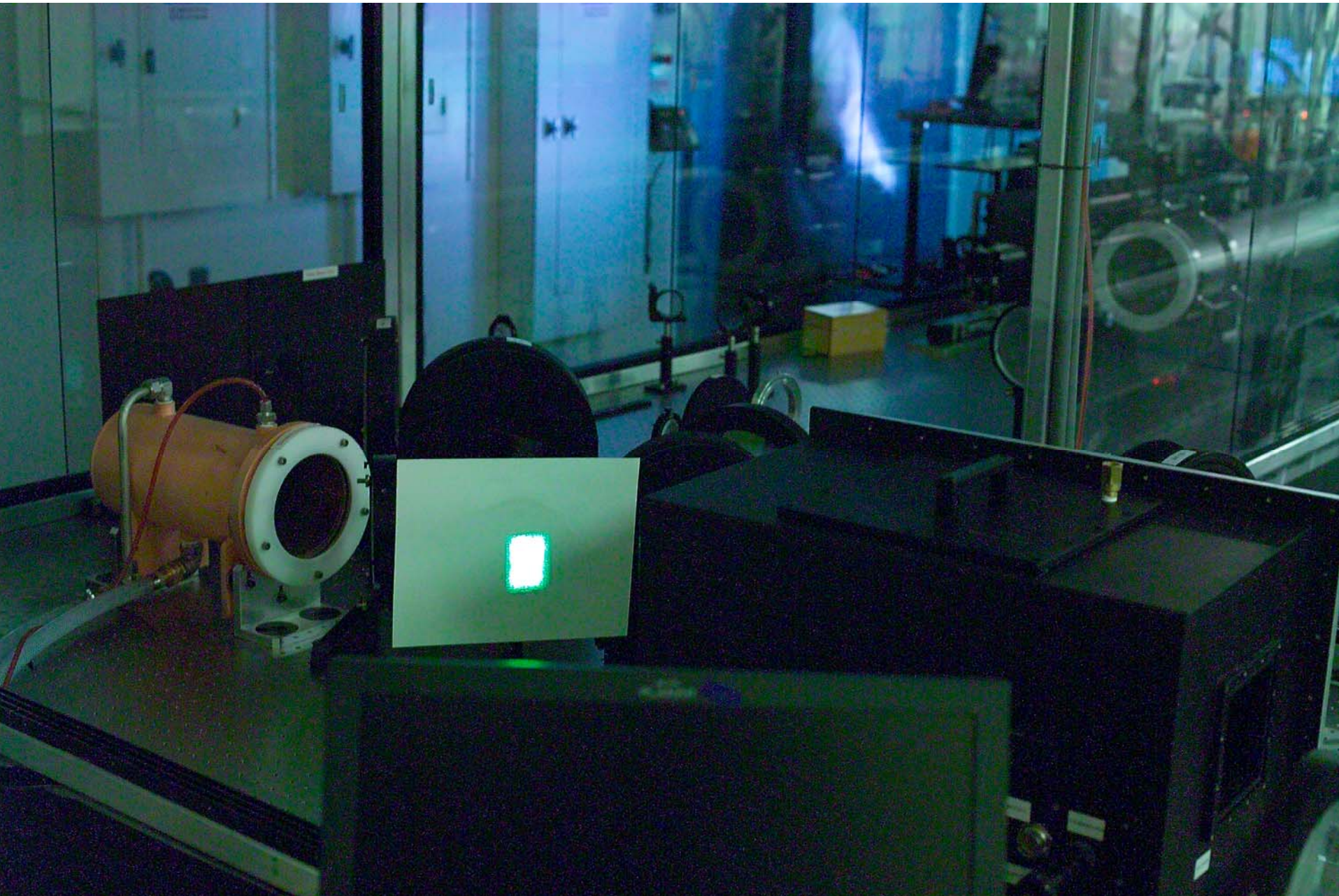
Temporal Pulse



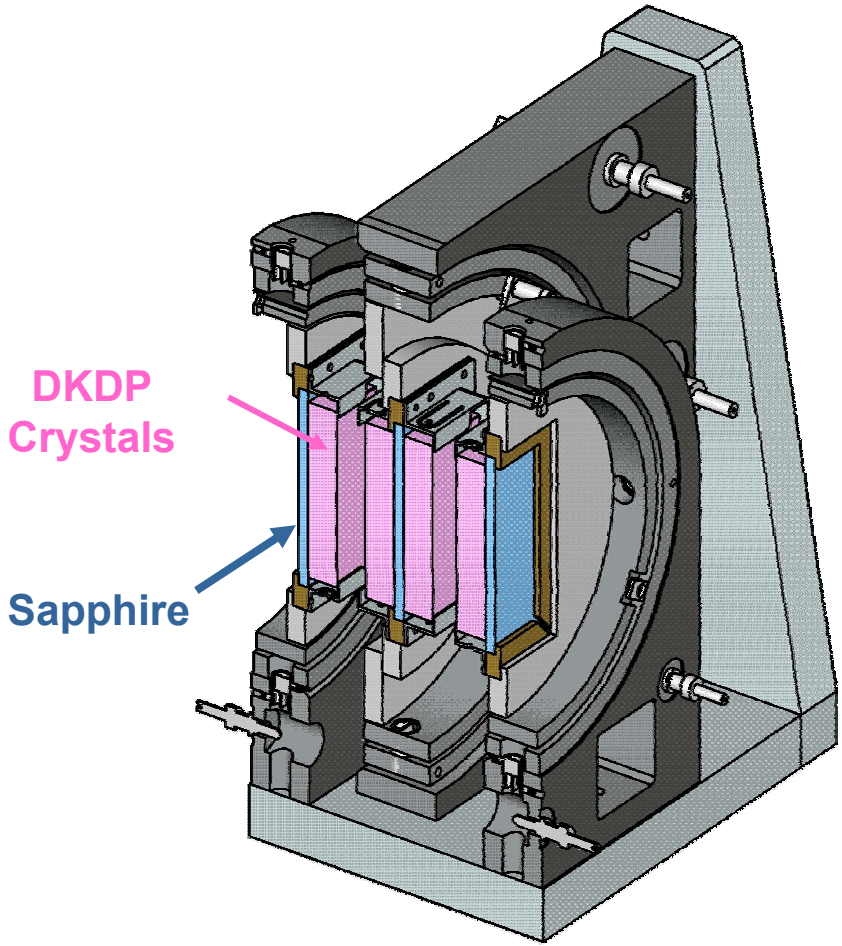
In total Mercury was operated for 55J for > 10^4 shots or 8 hrs with a peak energy shot of 63J

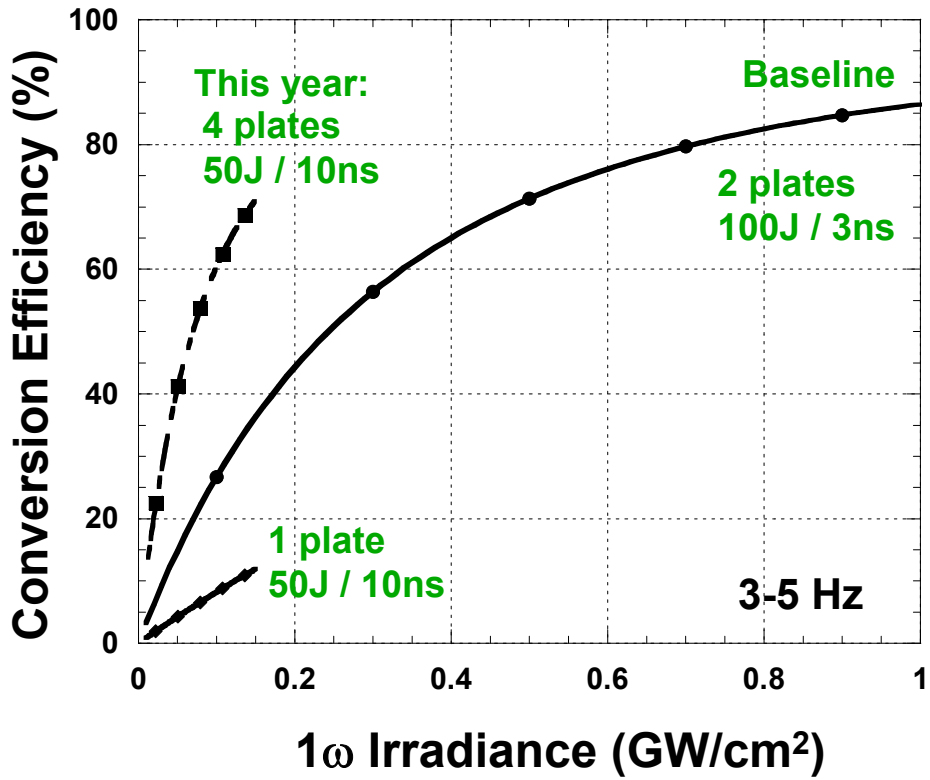


We have demonstrated 2ω first light on the Mercury Laser



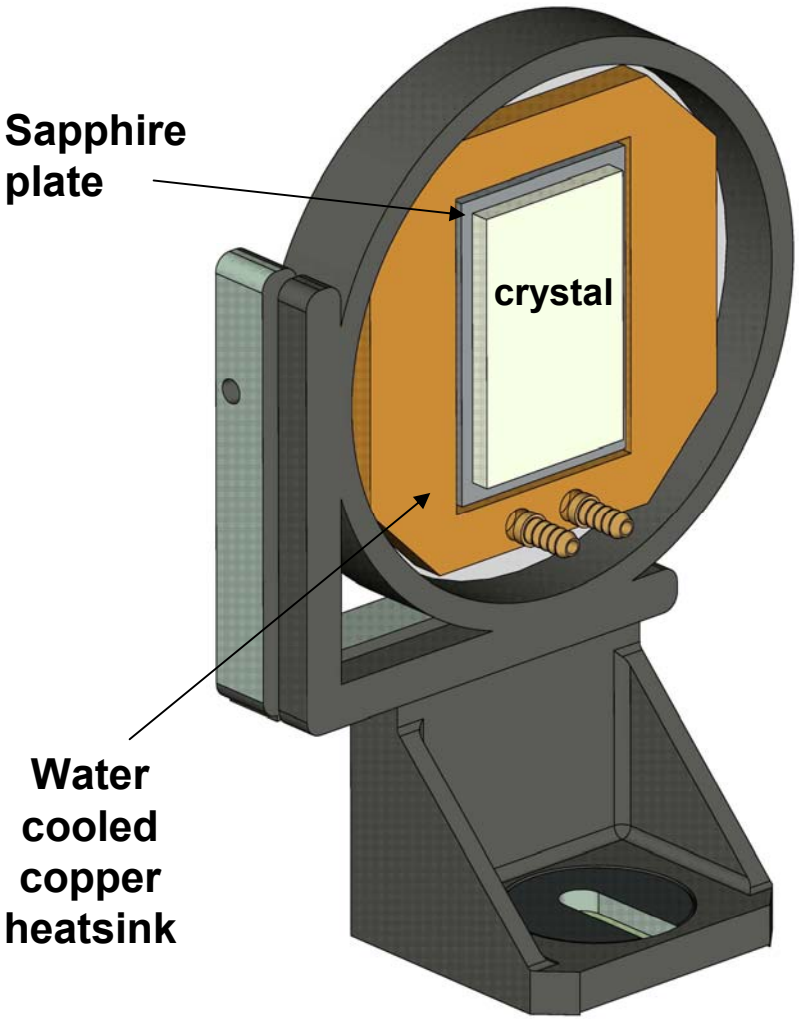
Our baseline material DKDP is comprised of 4-plates and can reach over 80% conversion



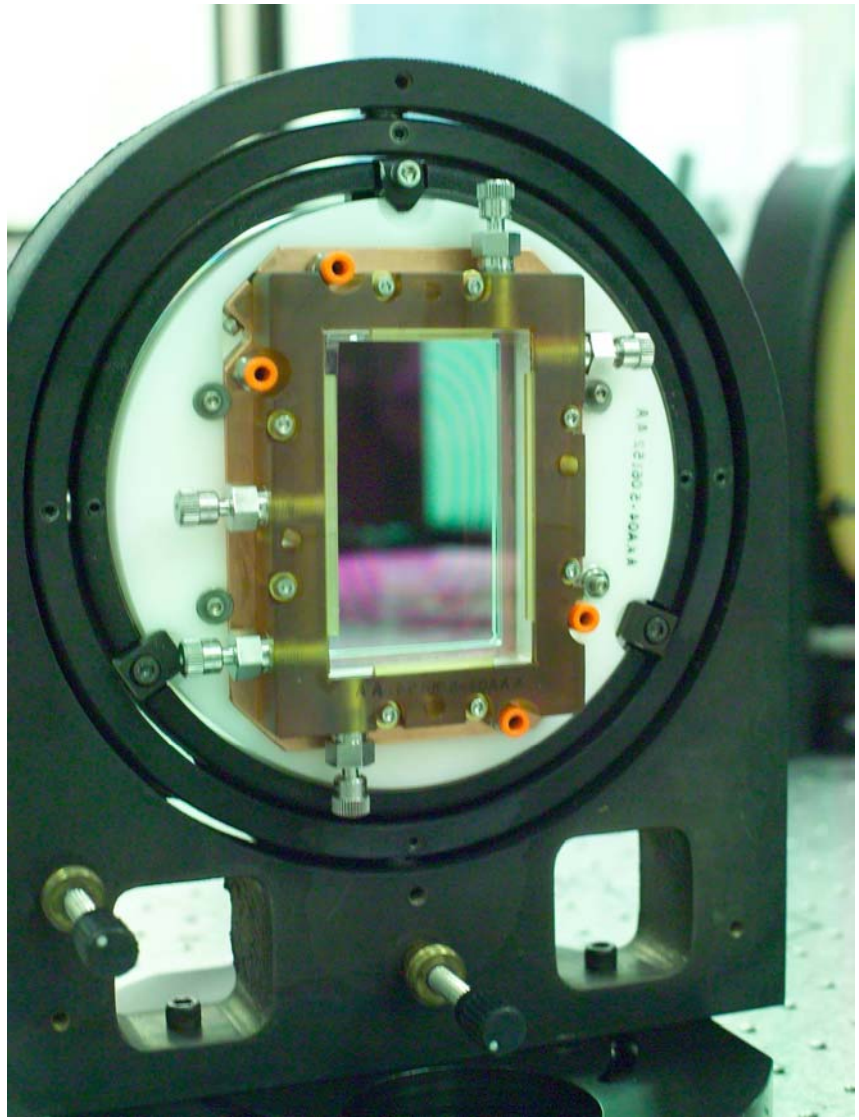


Initial experiments are being performed with one out of four plates of DKDP

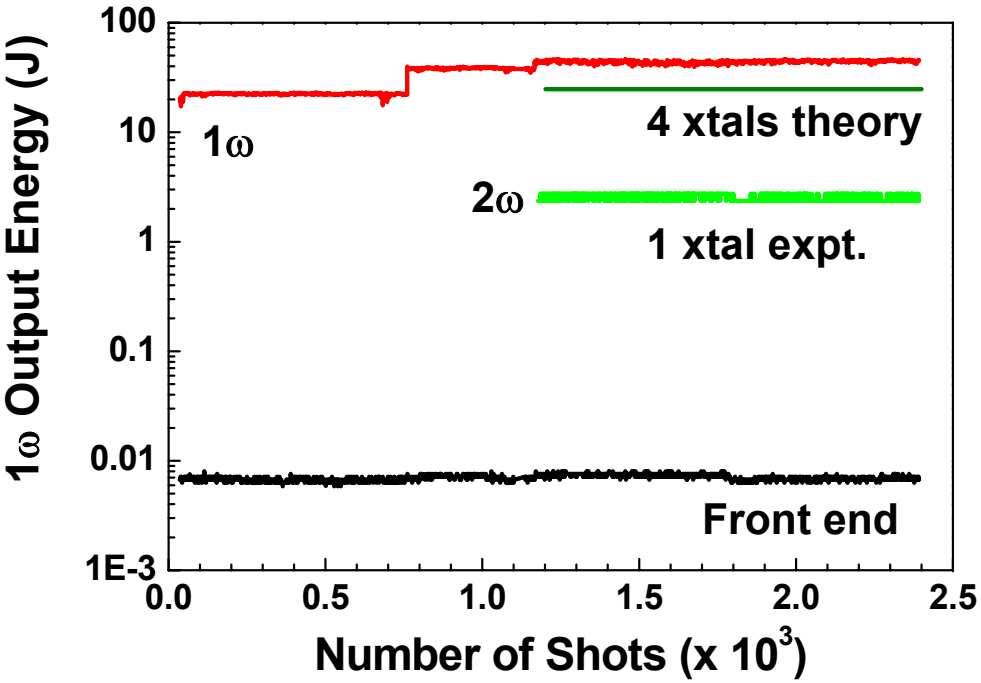
1-plate demo



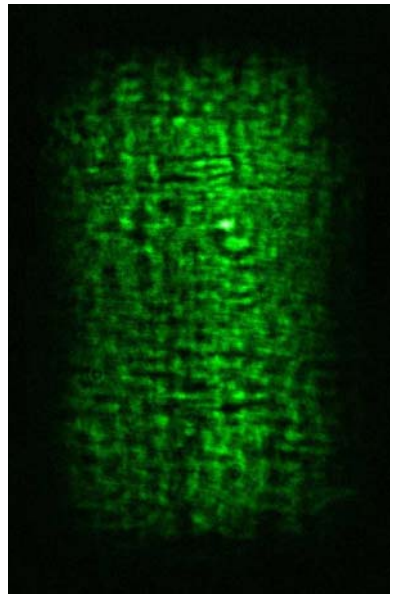
Hardware



We successfully fired over 1000 shots at the second harmonic for 1 Hz rep-rate

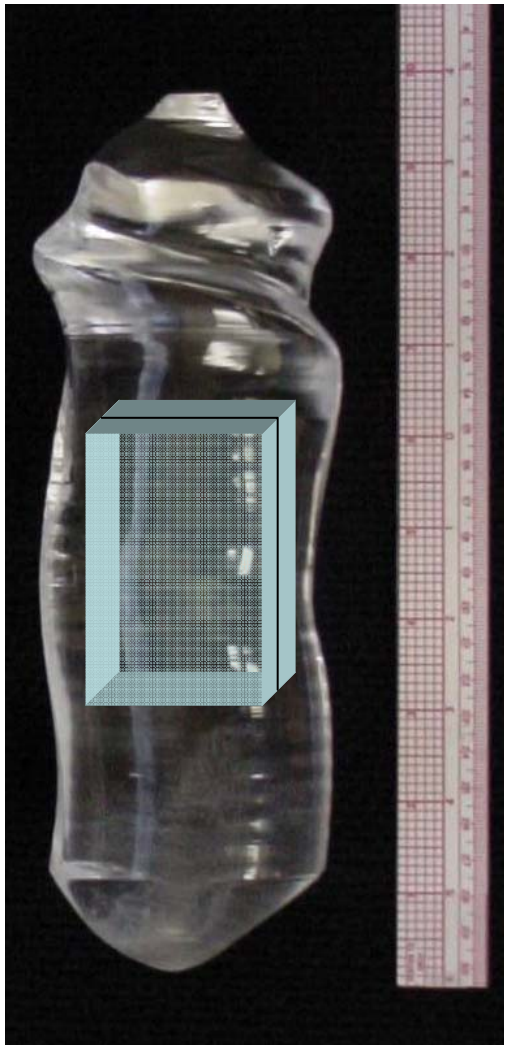


2ω Nearfield

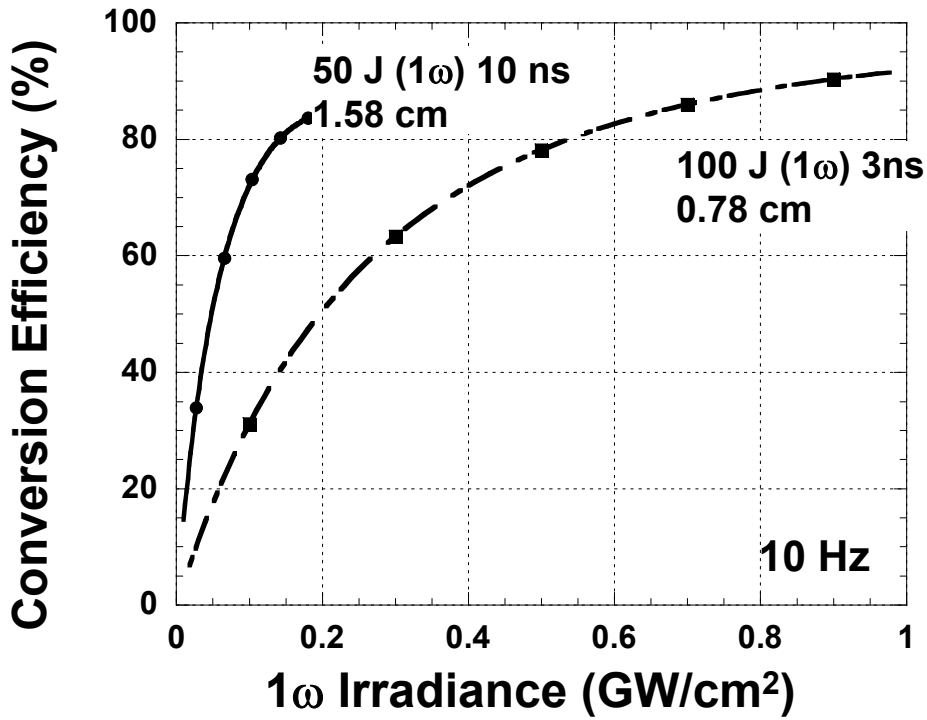


Upcoming experiments will increase the rep-rate and number of crystals to reach higher conversion

Advanced concepts are being pursued with the frequency conversion material YCOB



	Deff (pm/V)	Growth Achieved (dia. cm)	Angular Acceptance (mrad-cm)	Wavelength Acceptance (nm-cm)	Temperature Acceptance (°C-cm)
BBO	2.05	2	0.7	2.15	51
KDP	0.26	50+	1.25	19.7	11.3
DKDP	0.23	50+	1.34	5.2	~11
YCOB	1.1	8.5	1.22	1.15	40

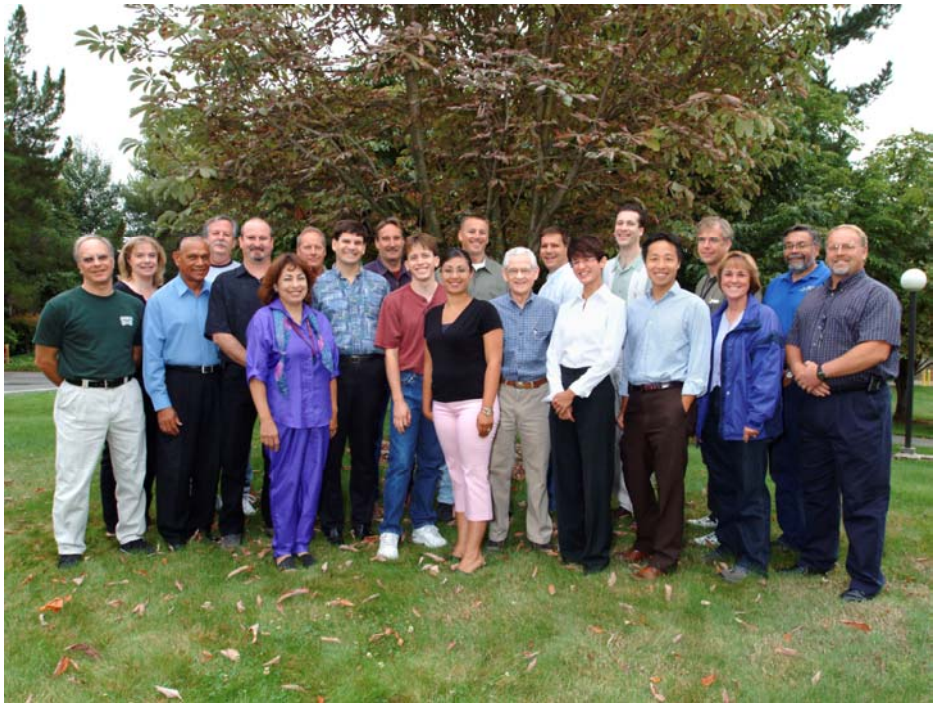


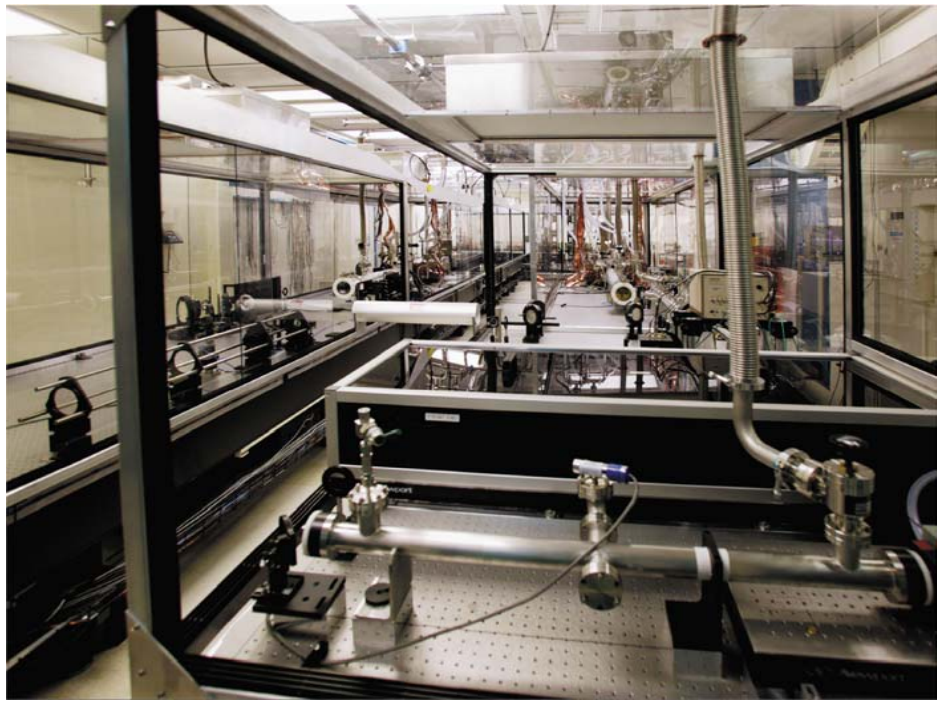
We are successively meeting our performance goals

		Goal	Present	End FY05
Components	Amplifier slabs	14	14 ✓	28
	Diode tiles	288	324 ✓	340
	Amplifiers	2	2 ✓	2
	- Cooling uniformity (rms)	<1%	.12% ✓	.12%
	Wavefront control	DM	On order	Offline demo
Performance	Energy (J)	100	55-63	100
	Rep-rate (Hz)	10	5-10	10
	Efficiency (%)	10	5	10
	Diode reliability (shots)	10^8	10^8 ✓	10^8
	Laser reliability (hrs)	8	8	> 10
	Beam quality (xDL)	5	5 @ 50J	10
	Pulse-shaping (ns)	3-10	20	10
	Bandwidth (GHz @ 1ω)	>150	250	Offline demo
	Conversion	2ω/3ω	2ω	2ω

✓ Completed

On Schedule





Mercury Team

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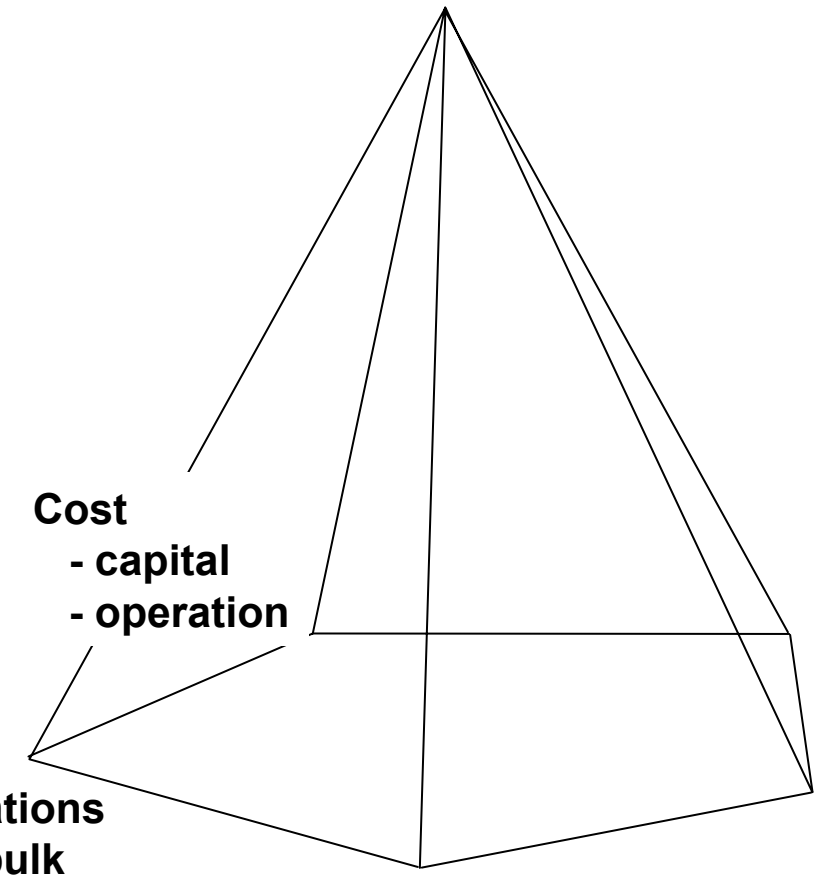
Quality Thin Films
Zygo
Photonic Crystals
Coherent
Directed Energy

Summary

- **Project Overview**
  - Mercury Laser performance goals and status
- **Component and system performance**
  - Pump diode arrays (Technology transfer to industry)
  - Crystalline gain media (14 spare slabs in queue)
  - Gas cooled amplifiers (Both amplifiers operating)
  - 1 μm operation (55 J at 3.5 Hz for over 5.5 hours)
  - Frequency conversion (First light at 2ω)
- **Next Generation Design Considerations**
  - Laser architecture building blocks

What are some of the building blocks for considering an architecture suitable for IFE



Cost
- capital
- operation

Gain Materials
- saturation fluence
- lifetime

Reliability (next meeting)
- optical lifetime
- N_{big} statistics
- optics count

Optical specifications
- surface and bulk
- coatings

Beam propagation
- linear and nonlinear effects
- modulation