UCRL-PRES-217043

Status of the Mercury Laser

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High Average Power Laser
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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 is the first step toward a 10 Hz class of IFE lasers

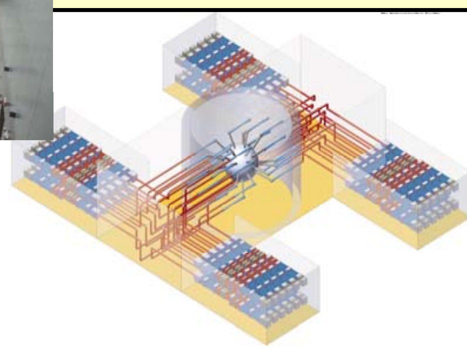
Mercury

100J IR

IRE (NIF bundle)

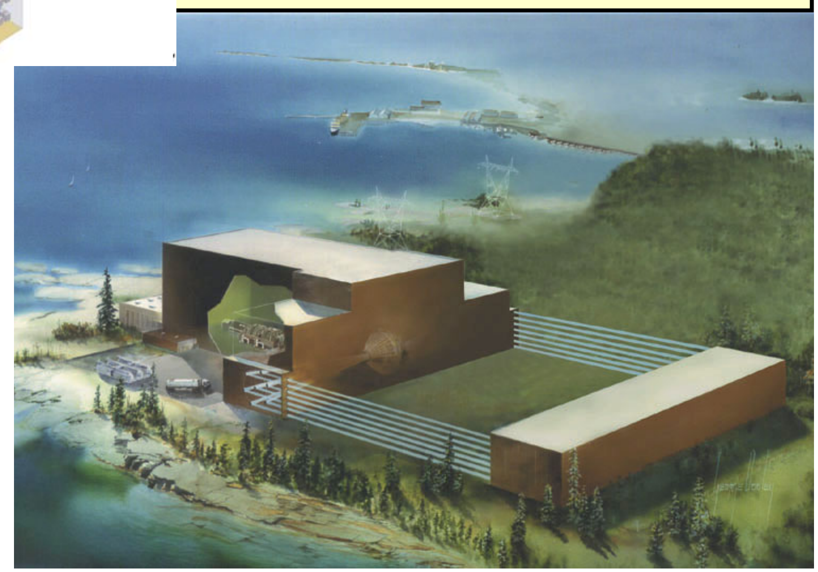
20kJ UV

ETF



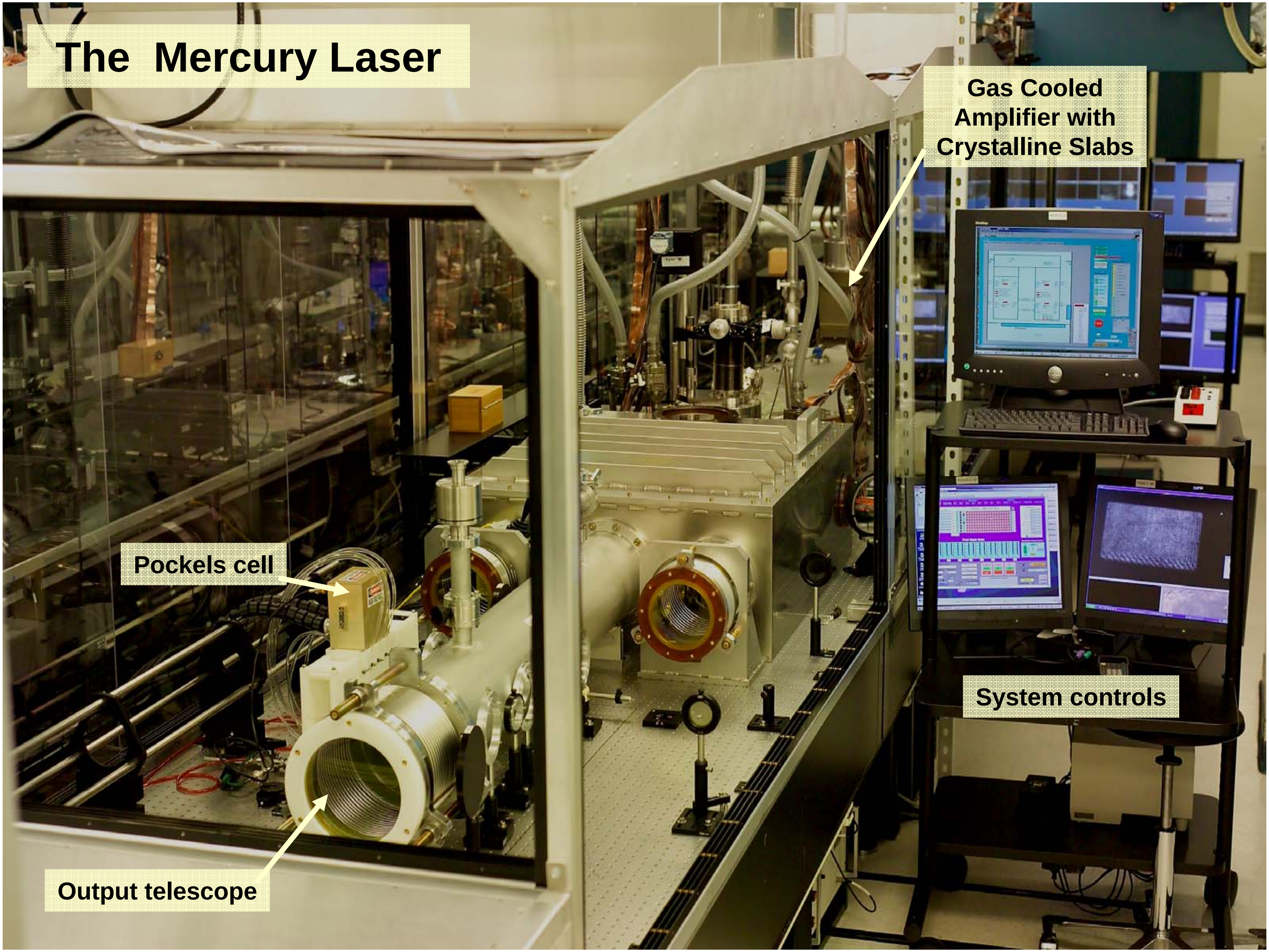
2MJ UV

IFE



	Mercury Goals	Status
Energy	100 J, 1ω	65 J, 1ω
Efficiency*	10 %	6.5%, 1ω
Repetition rate	10 Hz	10 Hz
Pulse length	3-10 ns	3-15 ns
Wavelength	0.53/0.35 μm	0.53 um
Bandwidth	>150 GHz 1ω	Soon
Beam quality	5 xDL	4 xDL, 80%

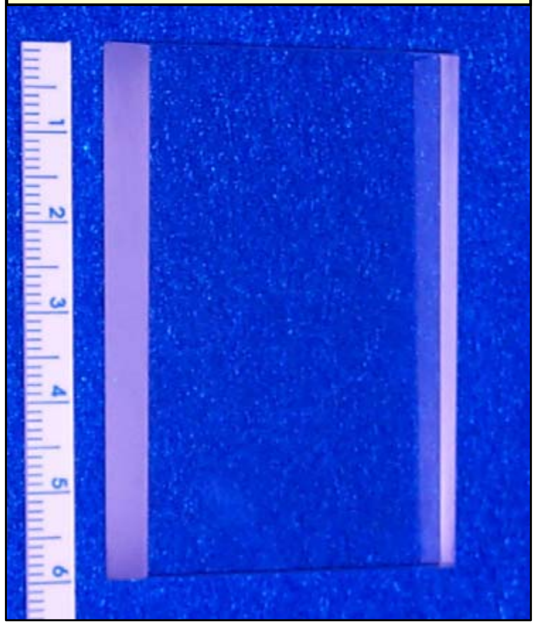
*utilities not included


The Mercury Laser
Gas Cooled Amplifier with Crystalline Slabs
Pockels cell
System controls
Output telescope

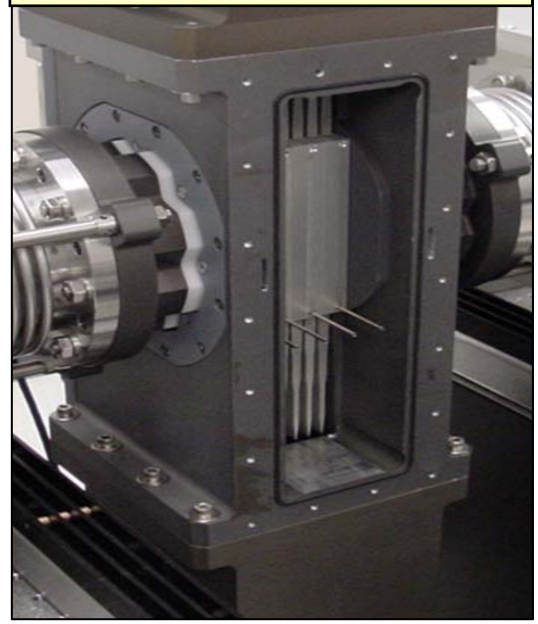
The Mercury Laser technologies

Diode pump arrays

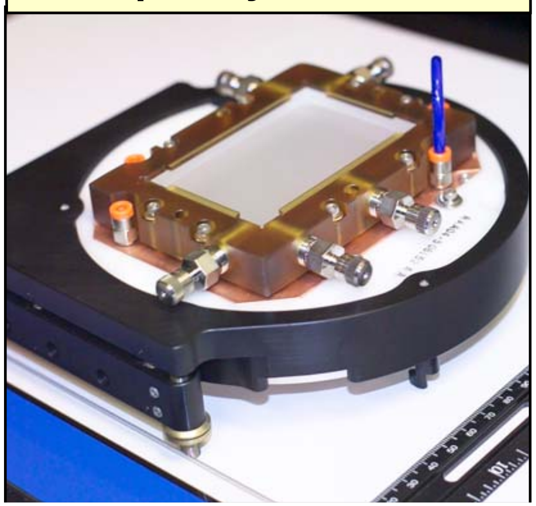
Solid-state amplifier



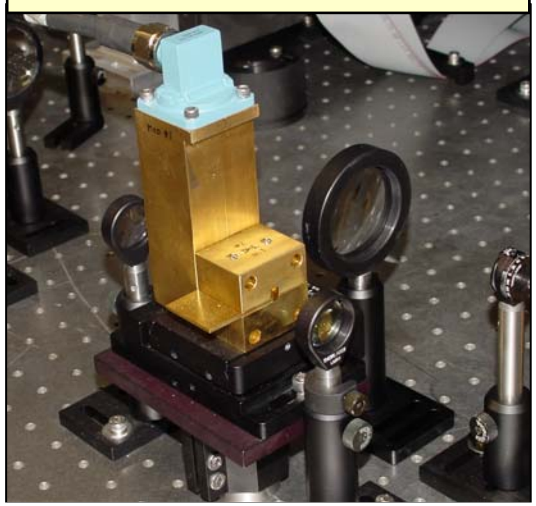
Helium gas cooling



Frequency Converter



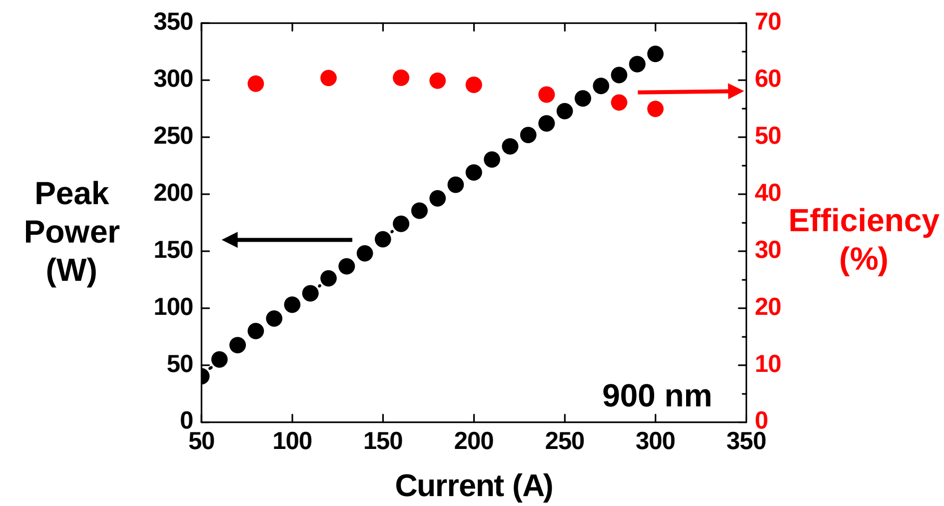
Broadband Front End



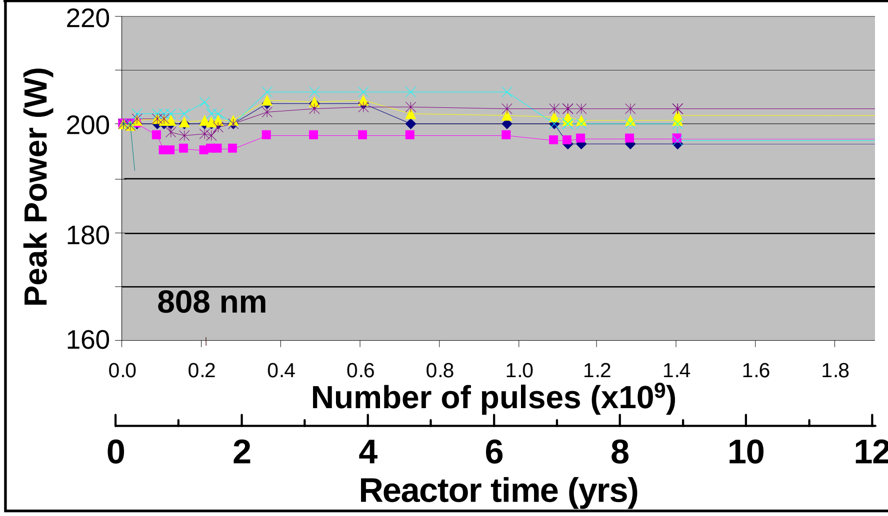
Adaptive Optic

New diode technology demonstrates enhanced reliability, efficiency, and lower cost per Watt

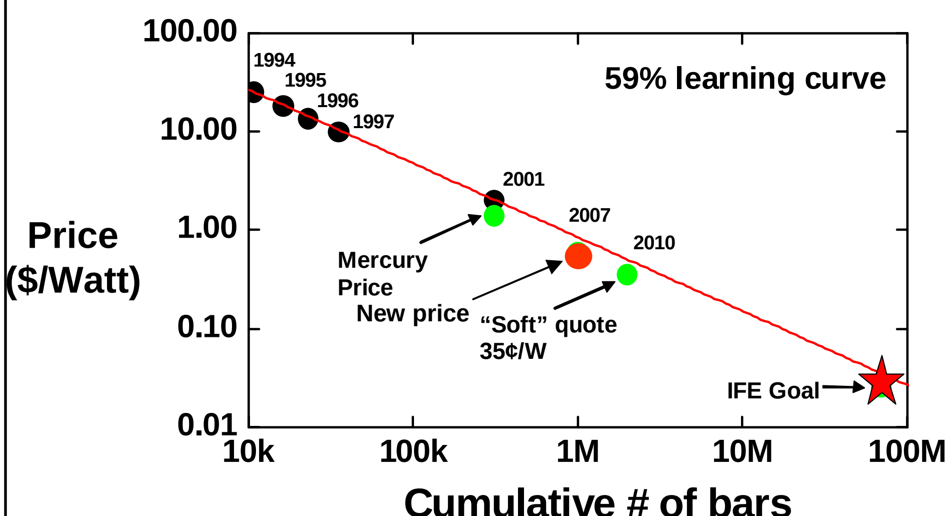
325W from 'Superbar' exceeds 300W goal



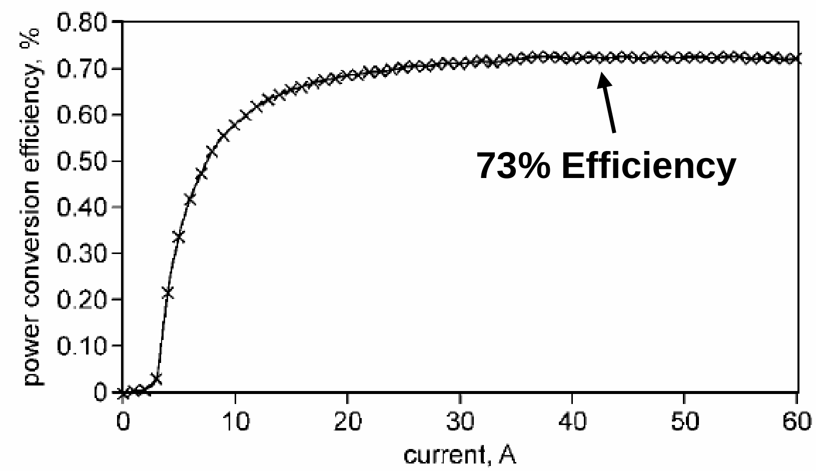
'Superbar' lifetime near 10^{10} shot goal



New price point falls in the learning curve



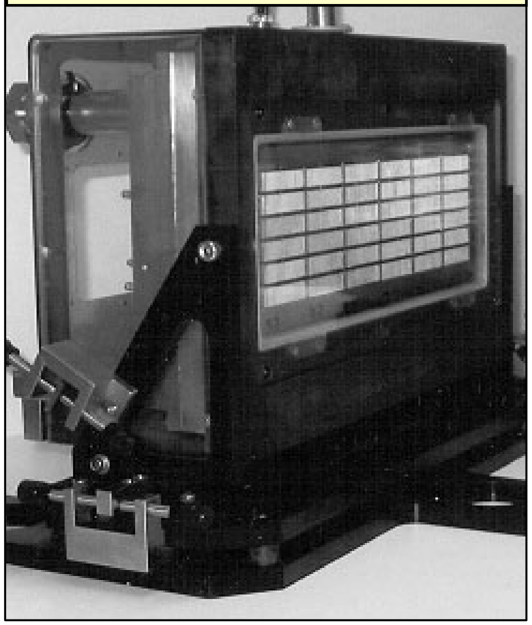
New efficiency data exceeds 70% goal



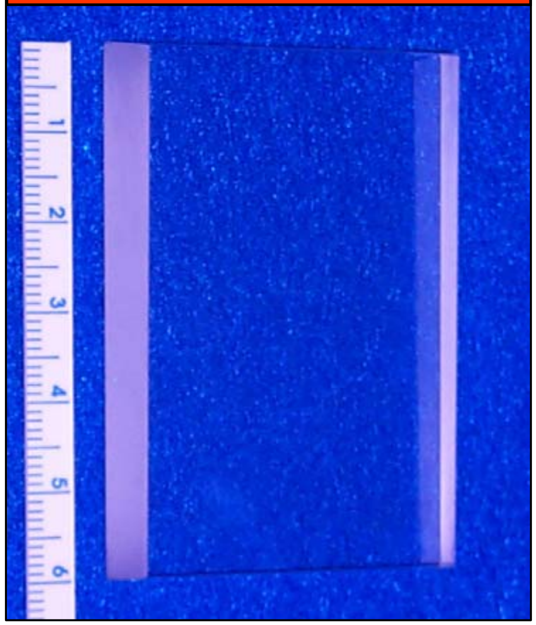
Kanskar, M. et. al. "73% CW power conversion efficiency at 50W from 970 nm diode laser bars", *Elec. Lett.*, **41**(5) 2005.

Commercial Yb:S-FAP growth efforts are currently focused on scaling to kJ apertures

Diode pump arrays



Solid-state amplifier



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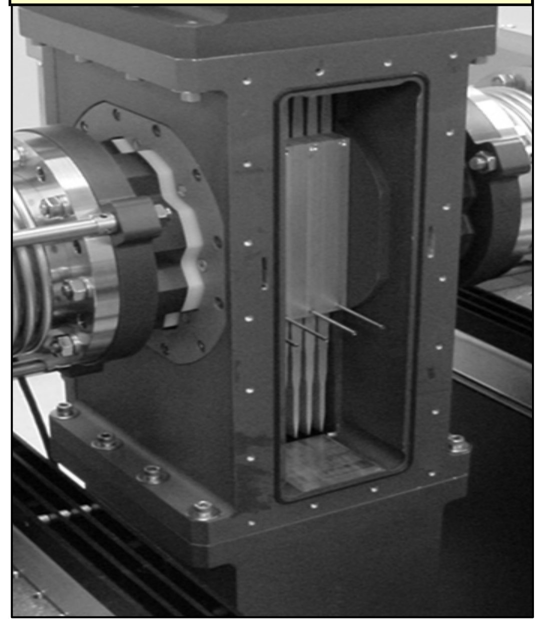
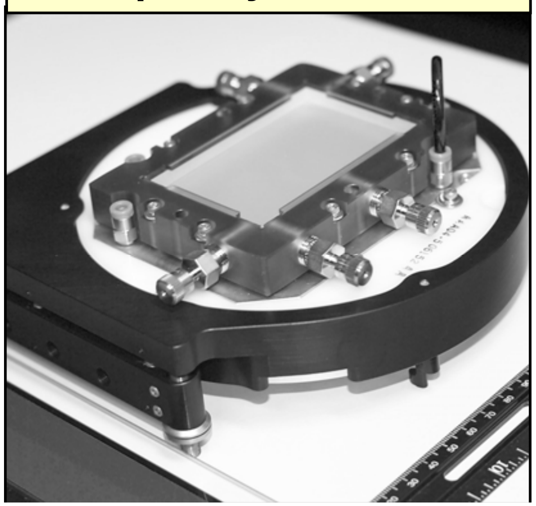


Frequency Converter



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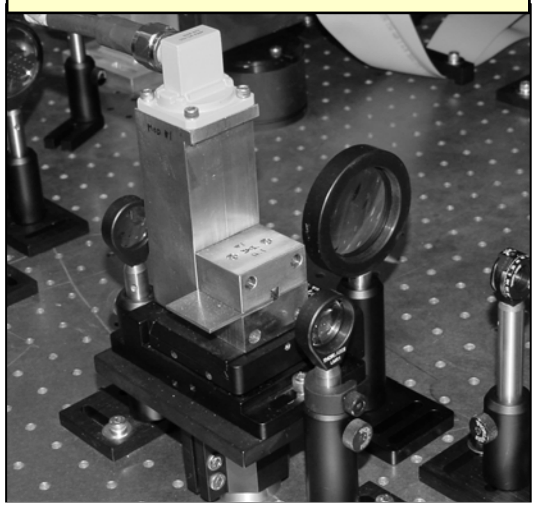
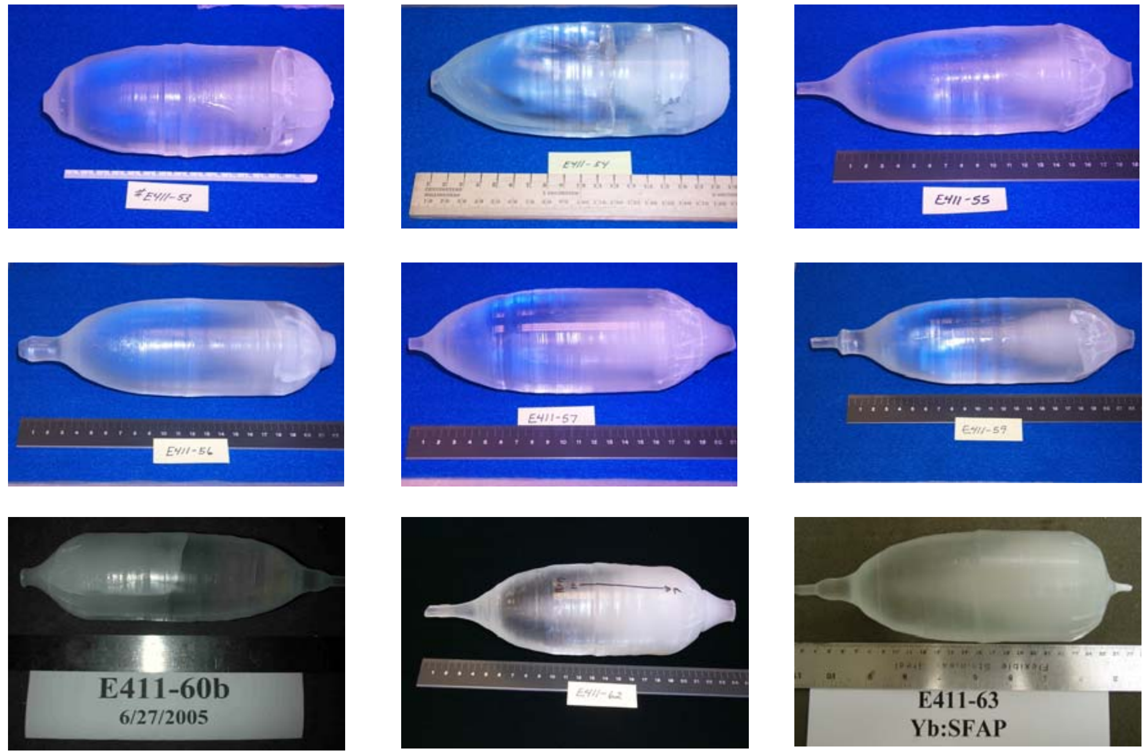


Adaptive Optic

Successful growth of Mercury-scale boules will lead to kJ-scale boules in 2006

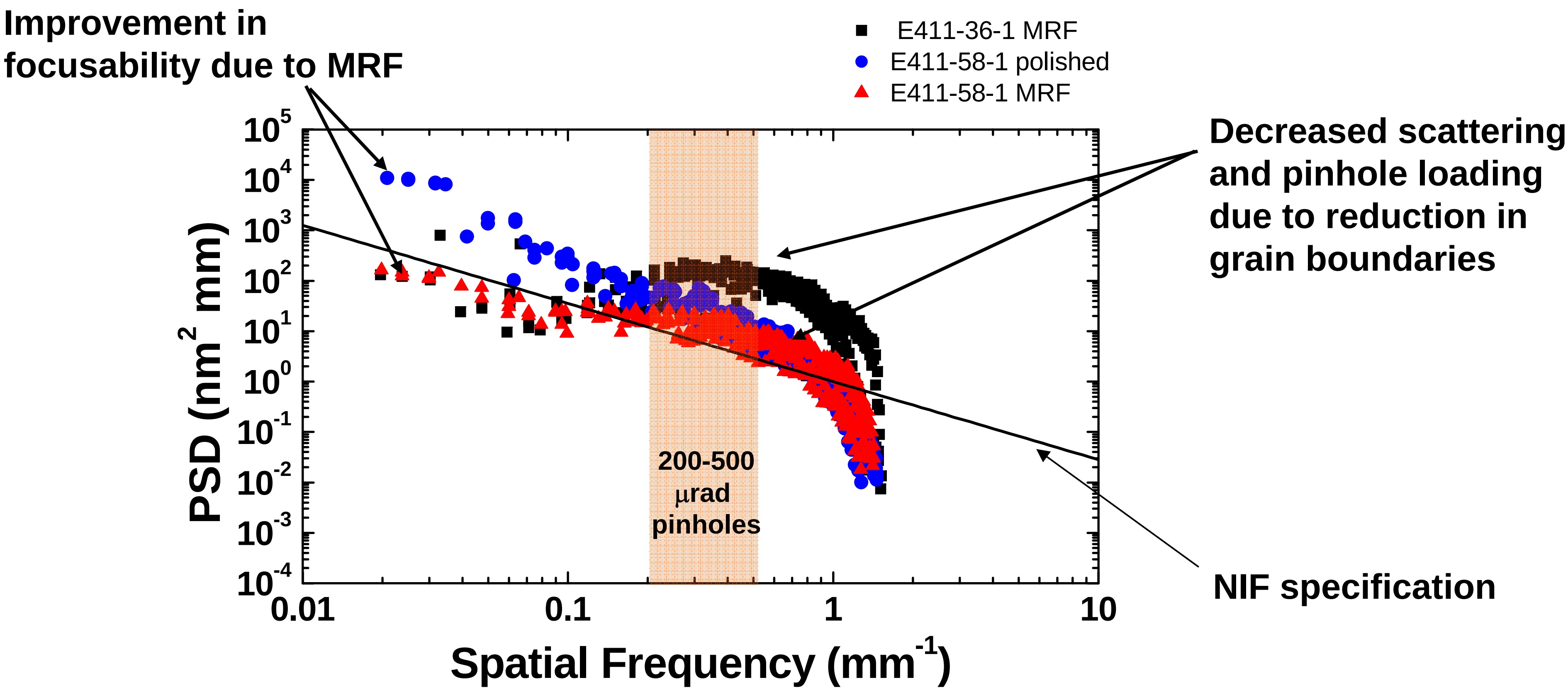
Northrop Grumman Czochralski growth station

Boules grown in FY05 which yielded slabs

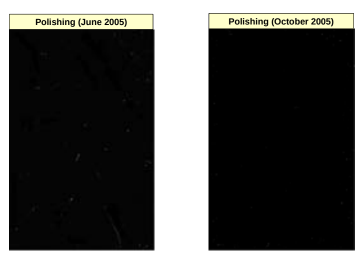


- **23 spare slabs are now in commercial production**
- **First 10 cm diameter growth in early CY2006**
- **10 cm diameter boules can produce 10 x 15 cm single crystal apertures or bonded 20 x 30 cm apertures capable of 1 - 4 kJ**

Optical quality of S-FAP has improved through reduction of grain boundaries, improved polishing, and magneto-rheological finishing



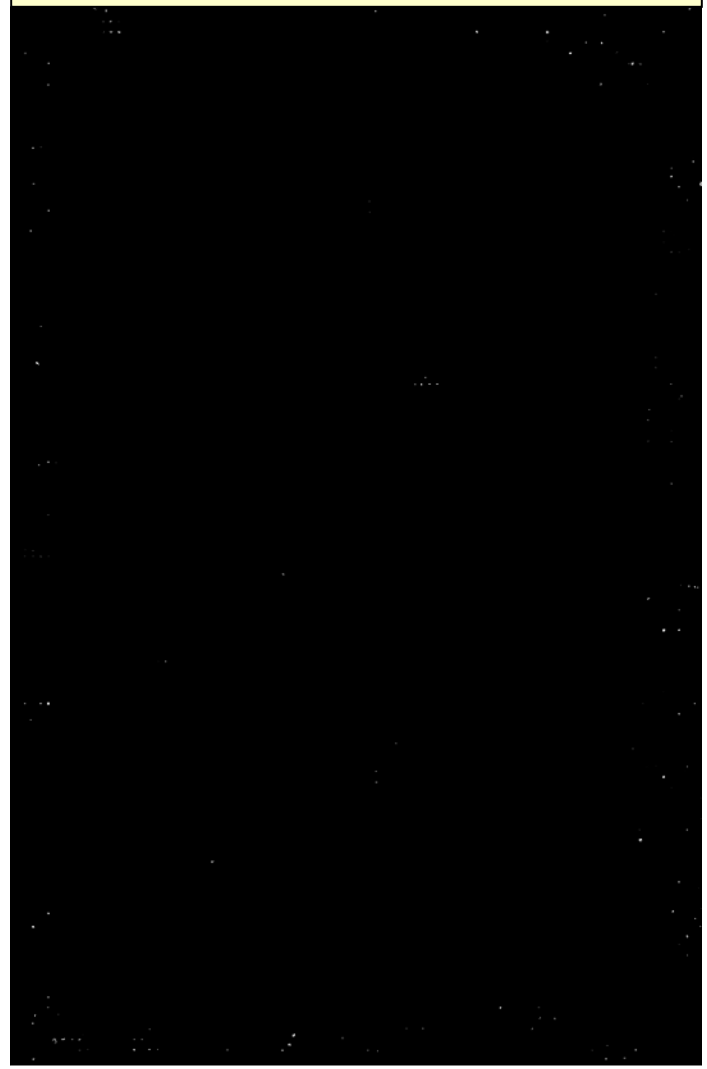
Improved polishing technique increases the laser damage threshold



Optical quality of S-FAP has improved through reduction of grain boundaries, improved polishing, and magneto-rheological finishing

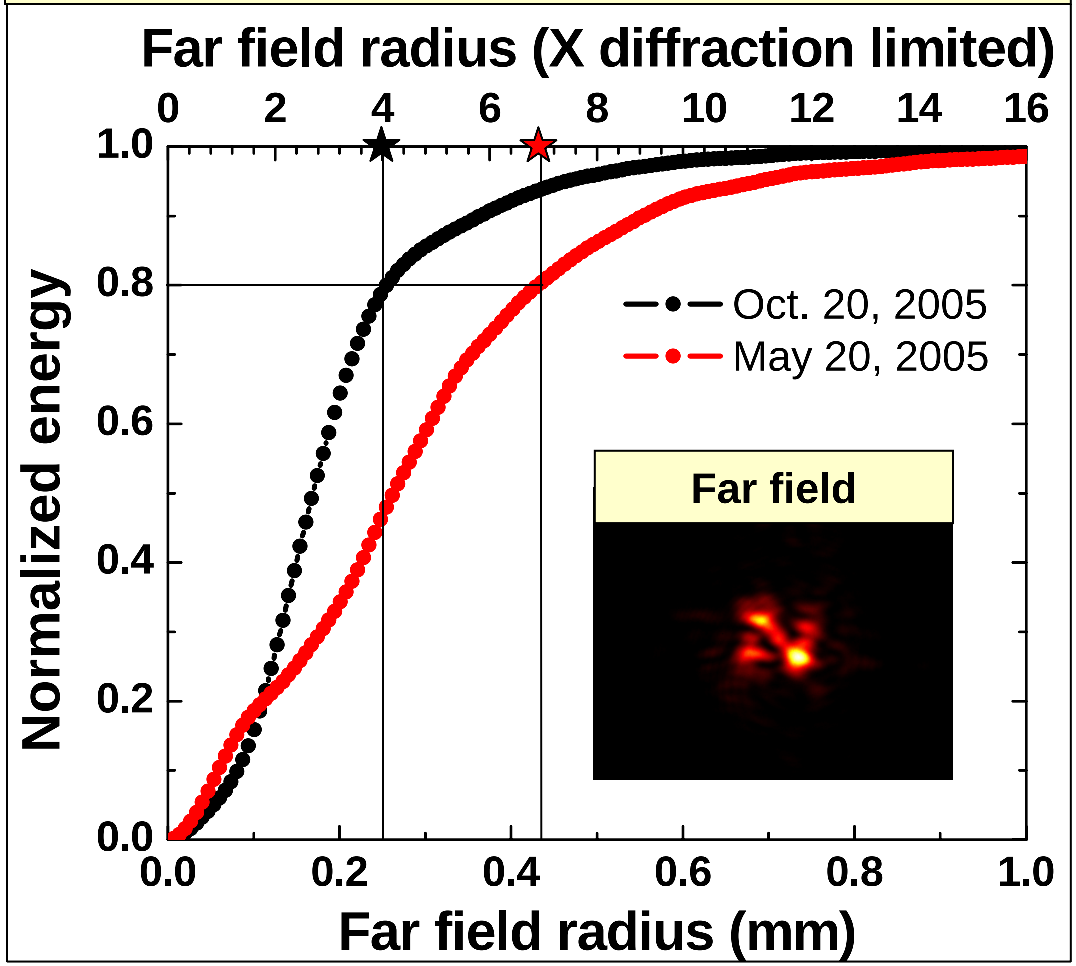
Polishing (June 2005)

Polishing (October 2005)

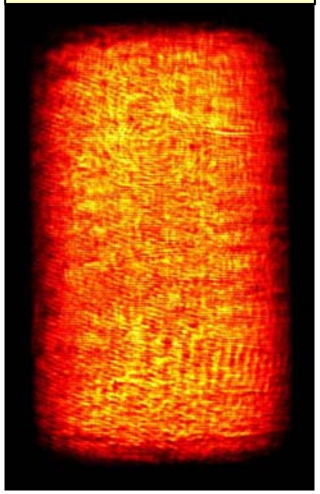


Far field analysis indicates that we will meet the < 5X diffraction limited goal

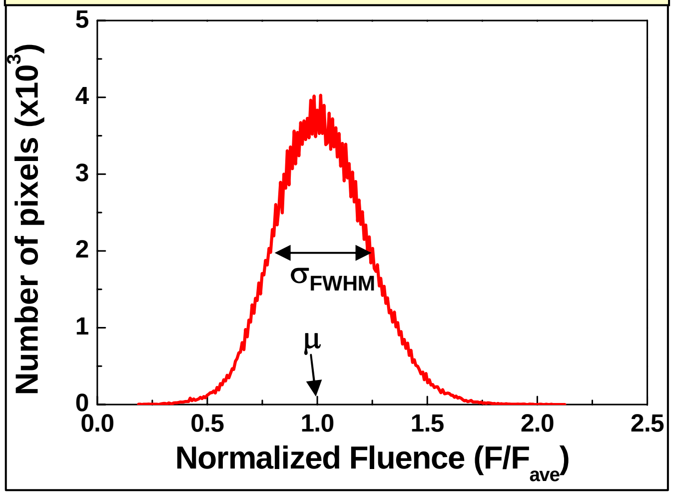
Radial integral



Near field



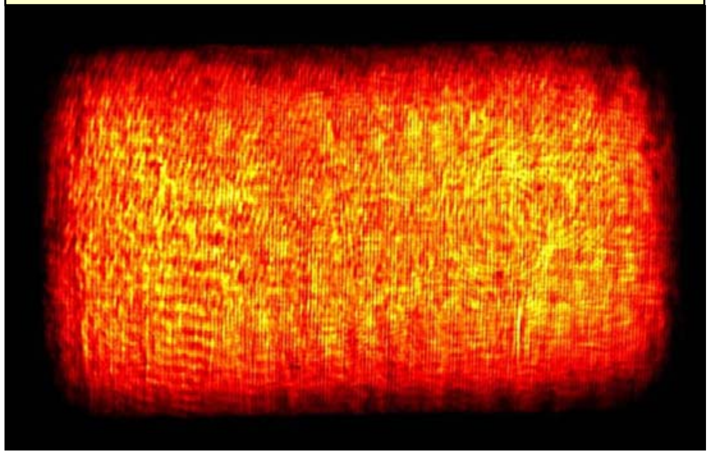
Experimental contrast (σ/μ) = 0.44
Improvements will appear in FY06



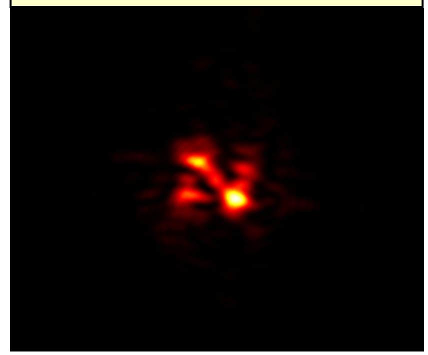
Improvements with new slabs and the adaptive optic

Output beam stability has been measured

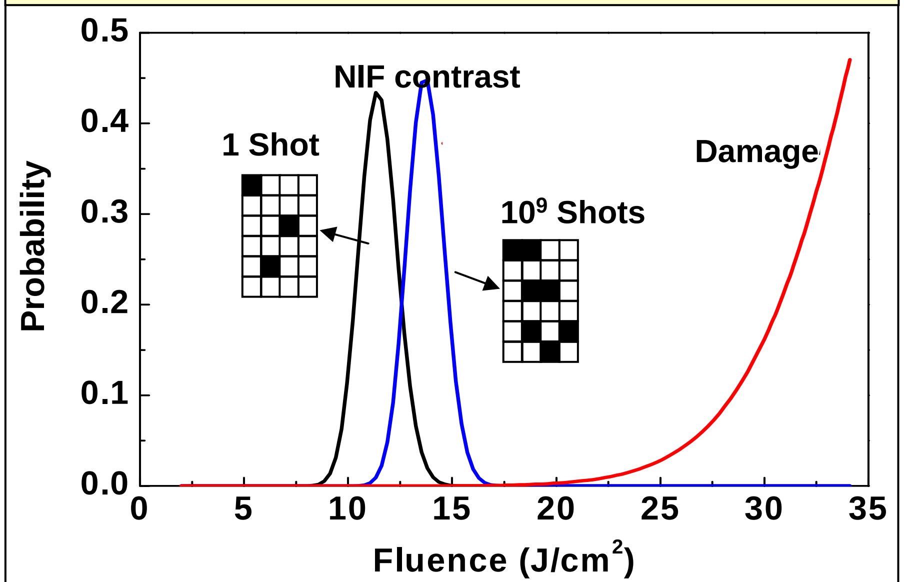
Output Near Field



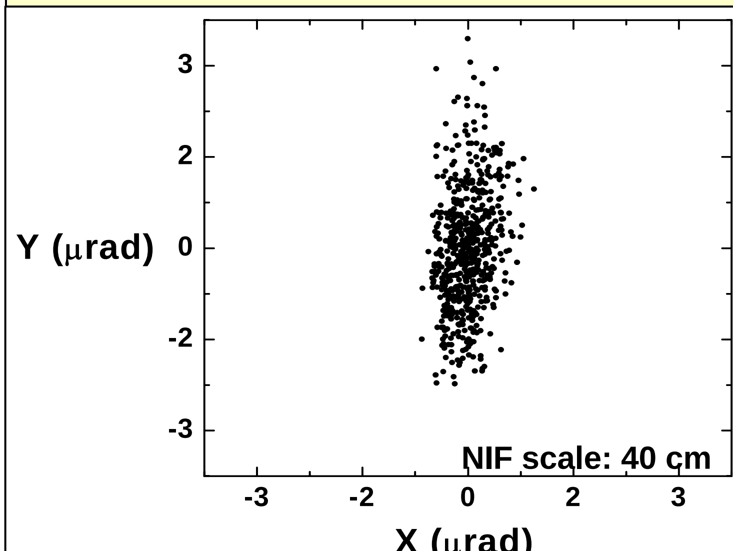
Output Far Field



Max of N analysis indicates small change in fluence for a large numbers of shots

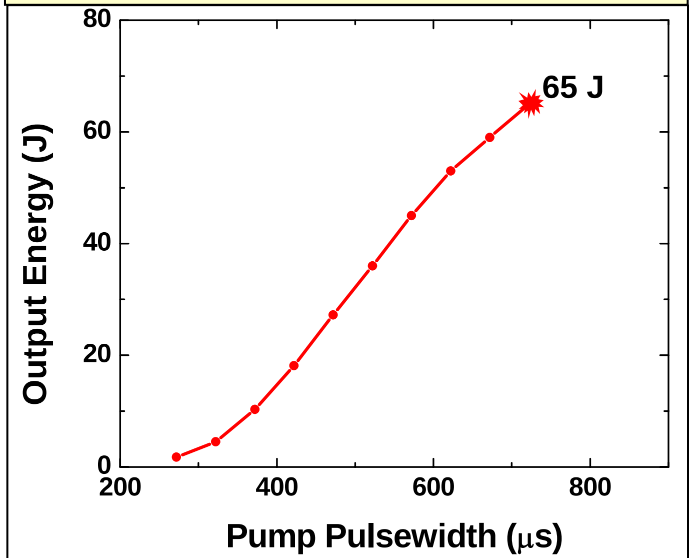


Pointing analysis indicates 0.65 μrad RMS stability

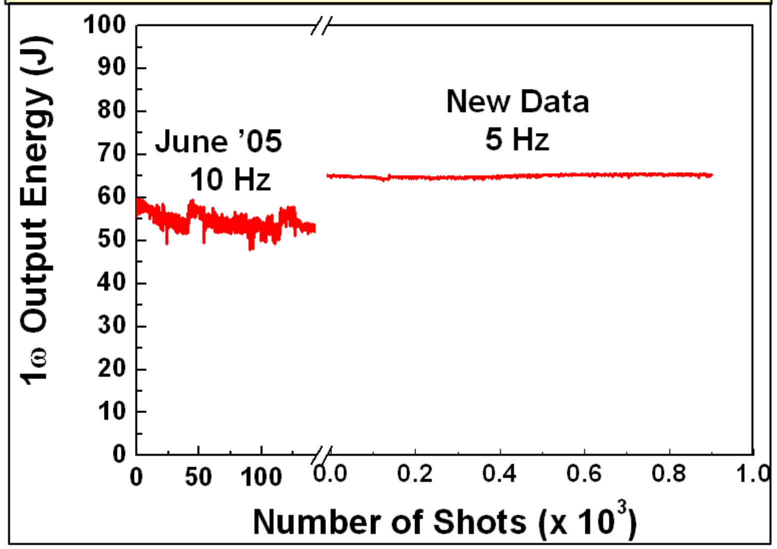


System upgrades have improved stability and reliability for high power operation

Single Shot Energetics



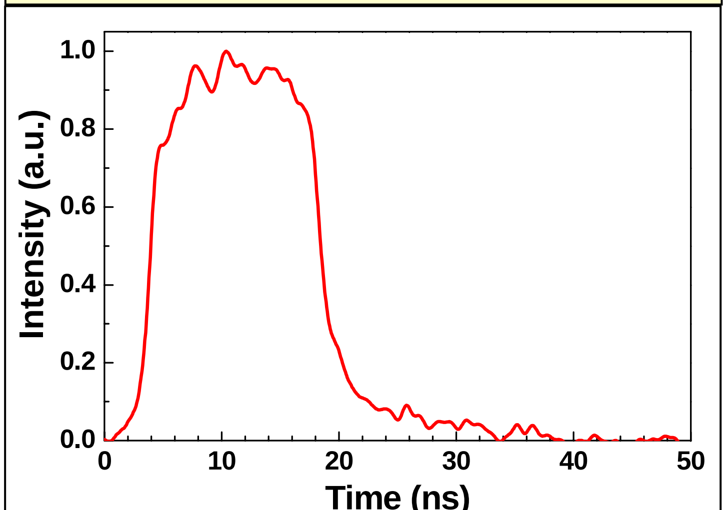
Average Power*



System upgrades

- Modified multiplexing and U-turn layout to reduce fluence on turning mirrors
- Improved shot and diagnostic stability through better shielding and electronics
- Automated alignment process for active correction of thermal abberations and long term drift

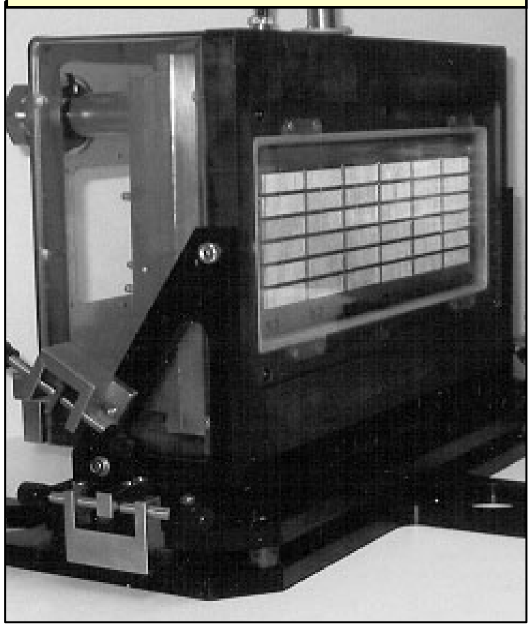
Temporal Shaping Capability



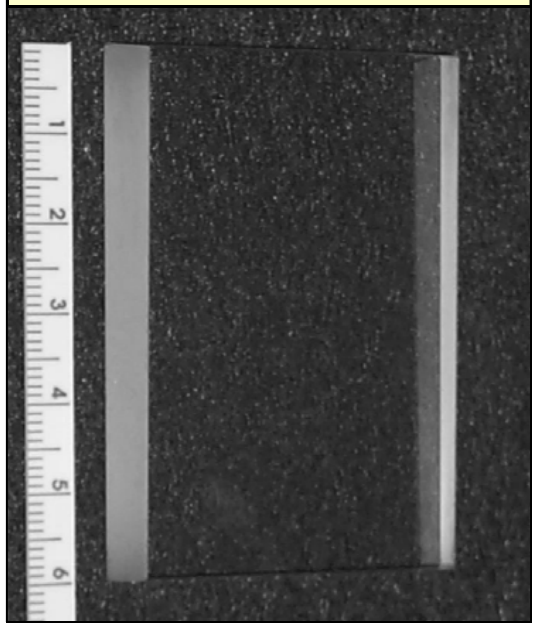
* Front end drop outs not shown

YCOB has generated over 220 W as an average power frequency conversion material

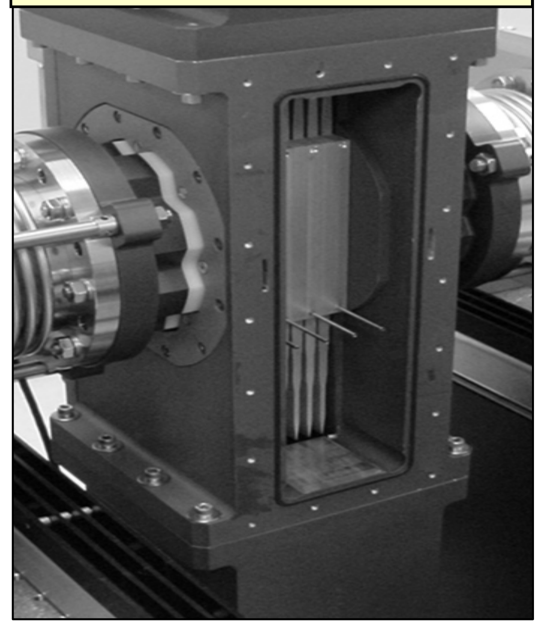
Diode pump arrays



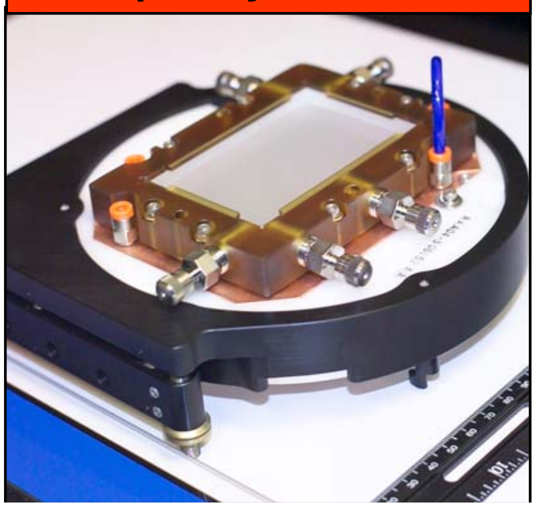
Solid-state amplifier



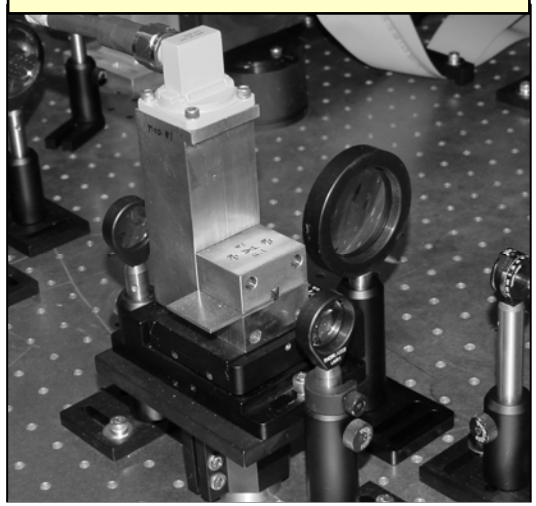
Helium gas cooling



Frequency Converter



Broadband Front End

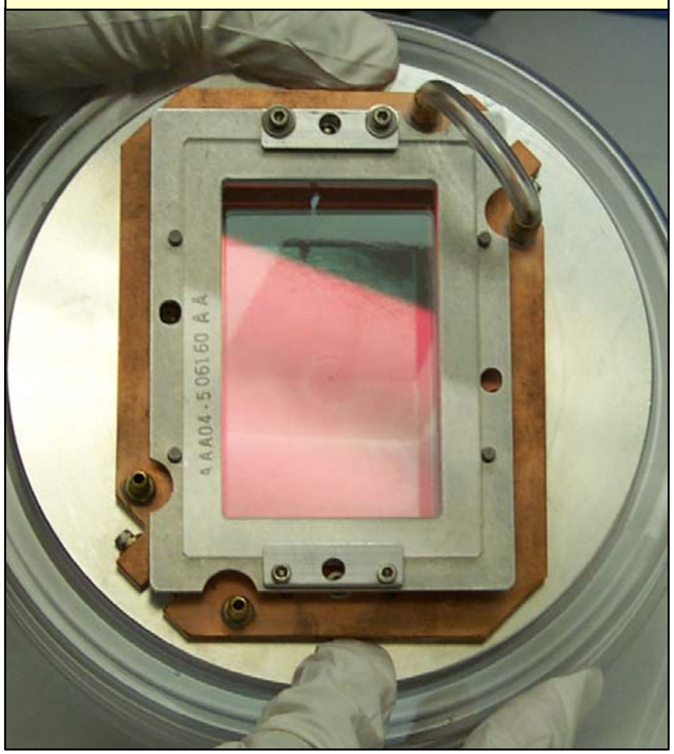


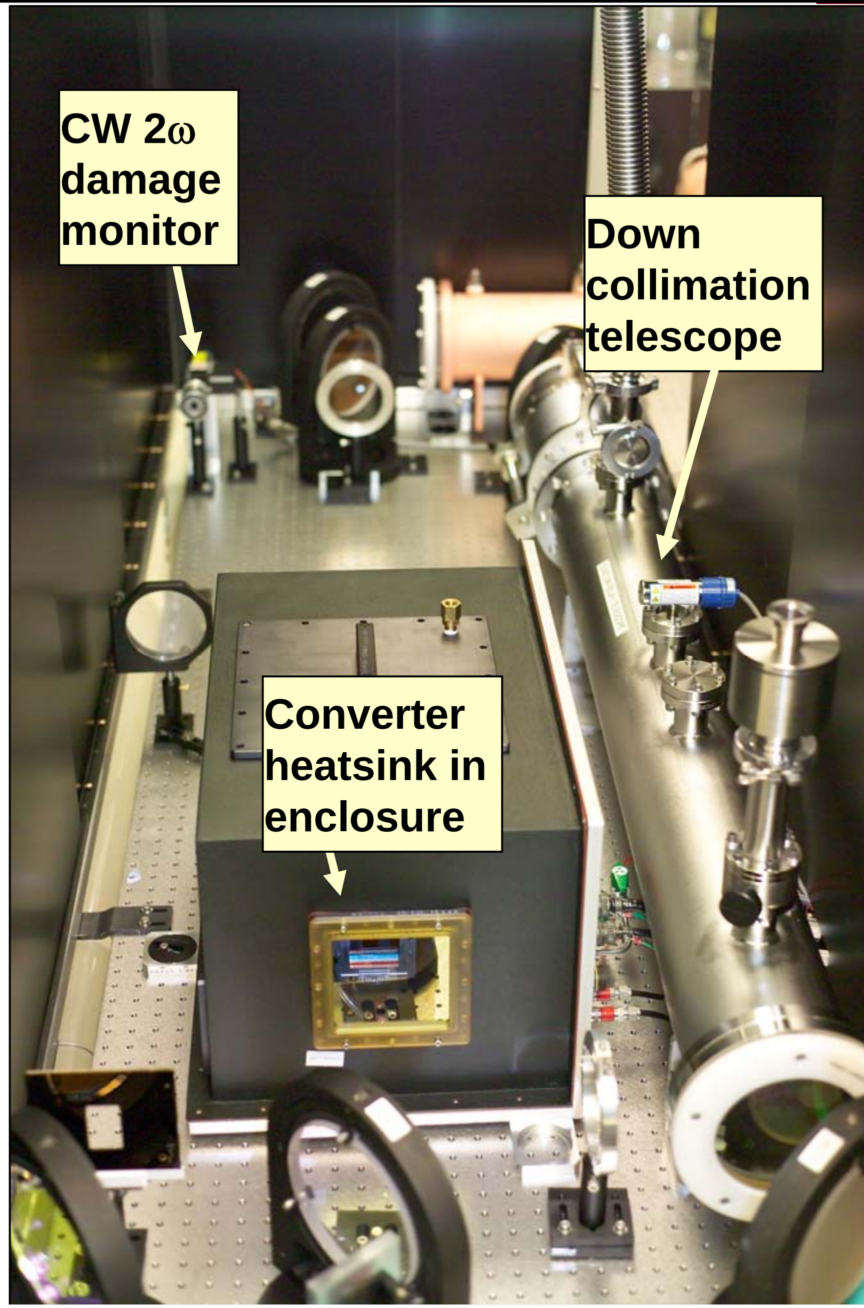
Adaptive Optic

We have fabricated three full aperture YCOB frequency converter crystals

- Aperture size is 5.5 x 8.5 x 1.1 cm^3
- Boules are production growth from Crystal Photonics Inc.
- Czochralski growth method is scalable to kJ apertures

YCOB Crystal in heatsink



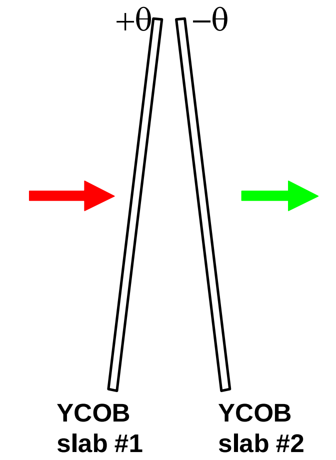


Multi-plate YCOB frequency converter is efficient up to a bandwidth of 384 GHz (1ω) meeting SSD requirement

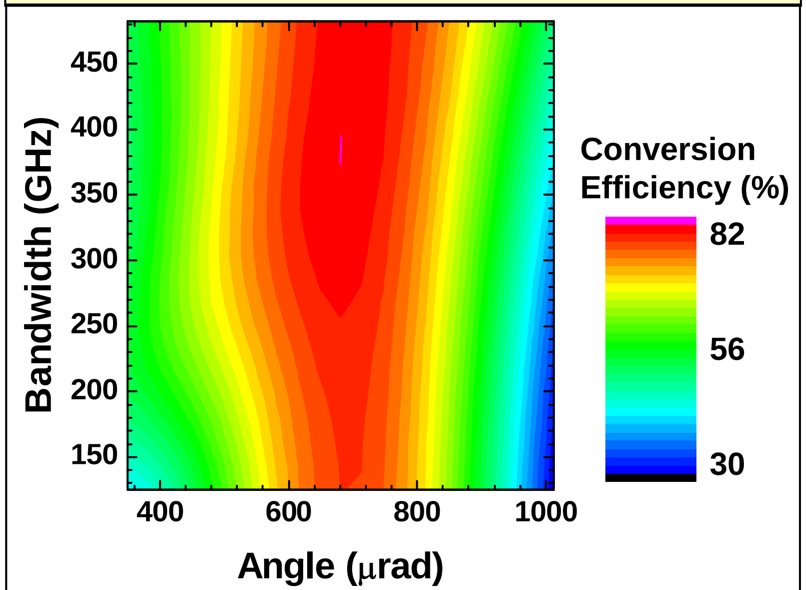
Goal : Determine the largest bandwidth and the best phase matching angle for two 7.5 mm thick YCOB crystals

<u>Result</u> : Parametric studies give
$\Delta\nu$ = 384 GHz, θ = 700 μrad

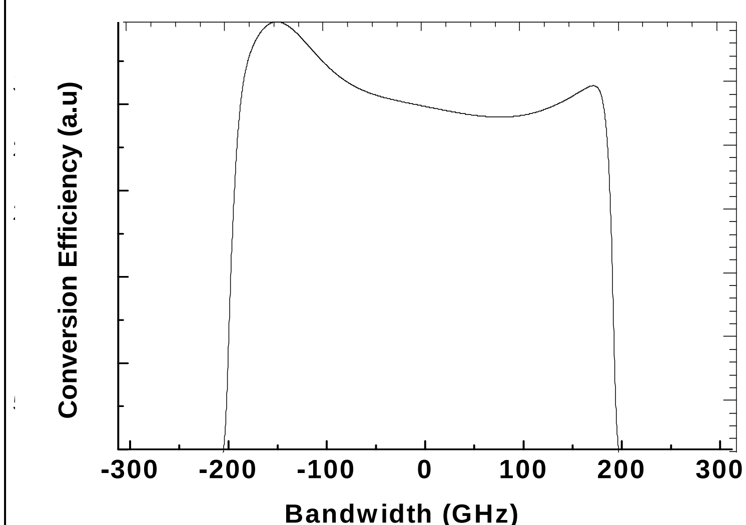
Multi-plate geometry



Efficiency optimization vs bandwidth

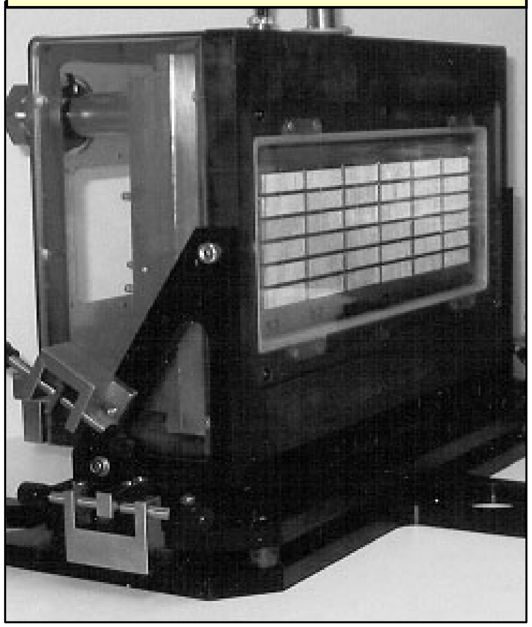


2ω spectrum at 768 GHz

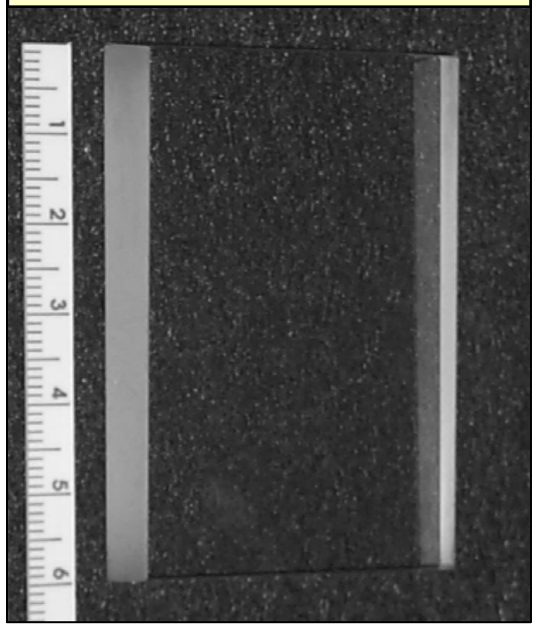


A temporally, spectrally, and spatially sculpted front end will allow efficient laser extraction and coupling to fusion targets

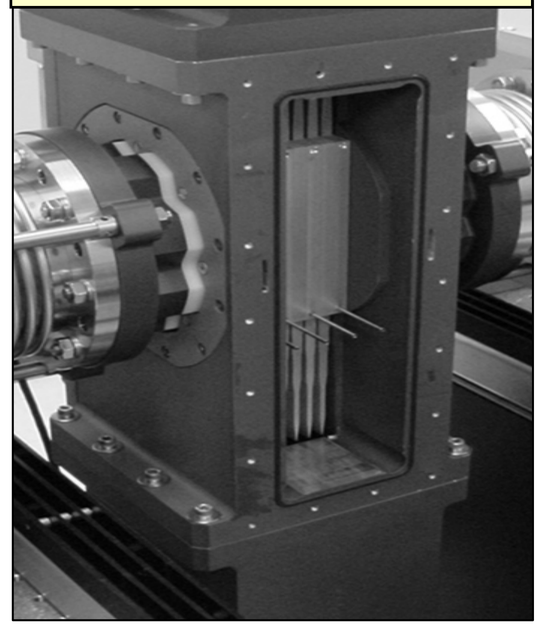
Diode pump arrays



Solid-state amplifier



Helium gas cooling



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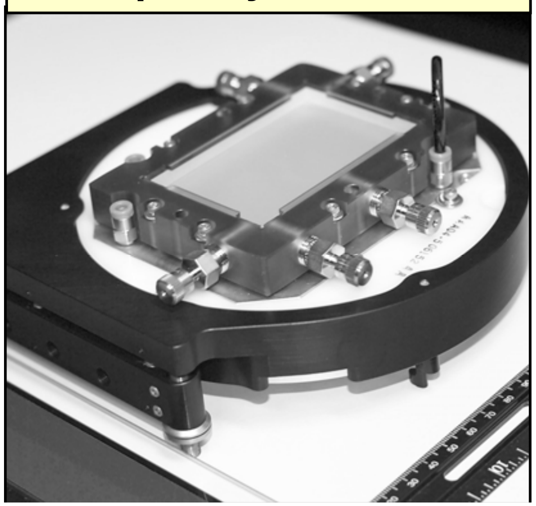
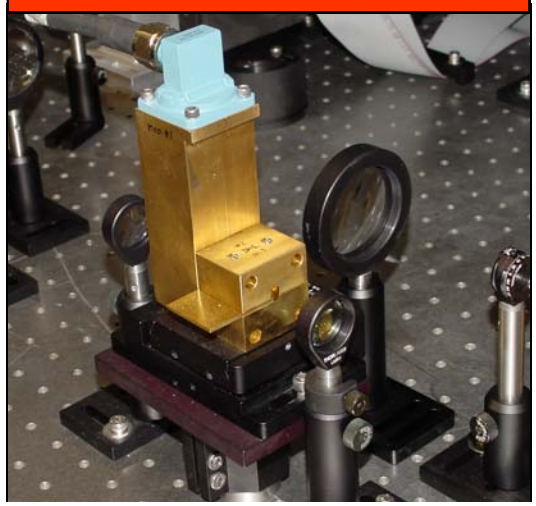


Broadband Front End



Adaptive Optic

Mercury's front end design uses fiber technology for a stable and robust system meeting NIF (IFE) requirements

Energy stability and beam quality required for reliable ignition pulses

- 500 +/- 2.5 mJ @ 10 Hz
- 10,000:1 signal to noise
- Beam quality: < 1.5X diffraction limited

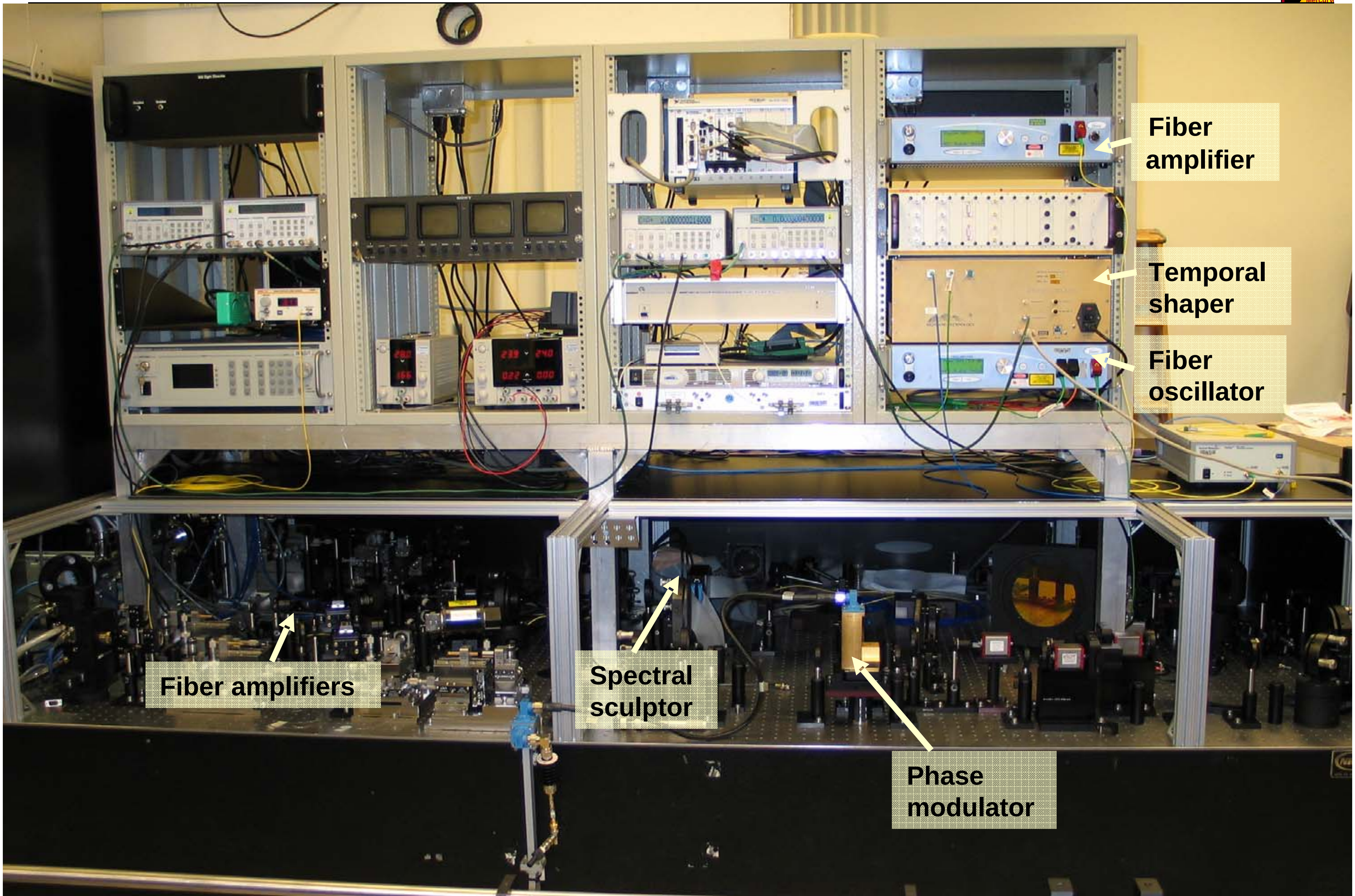
Temporal shaping required to compensate for gain saturation and ignition waveforms

- < 5% amplitude fluctuations
- > 250 ps jitter
- 20:1 contrast

Spectral bandwidth required for beam smoothing on target

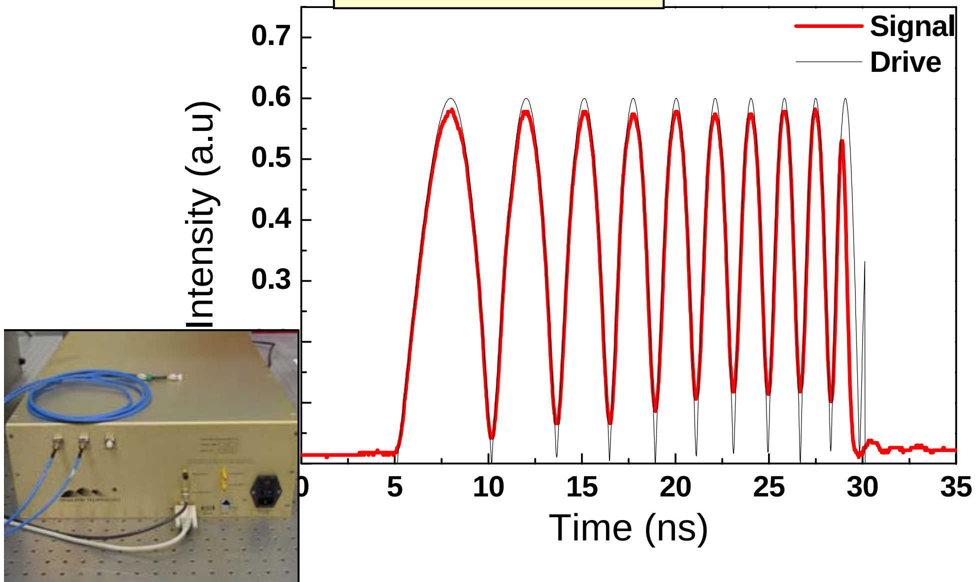
- 3 GHz stability
- >150 GHz bandwidth
- 100:1 contrast

Fiber osc – Temporal shp – Fiber amp – RF bandwidth – Spectral sculpt – Fiber amp – S-FAP Ring

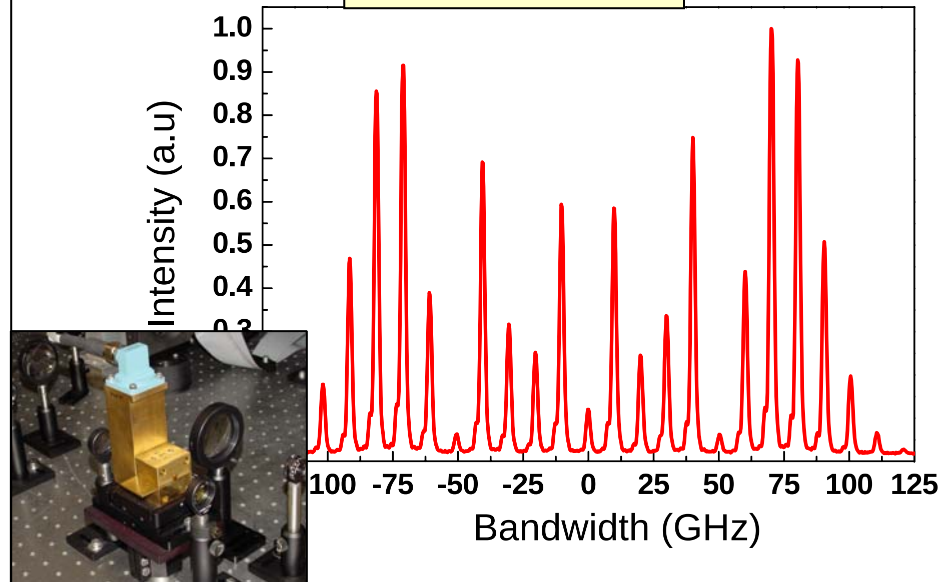


Front end development progress

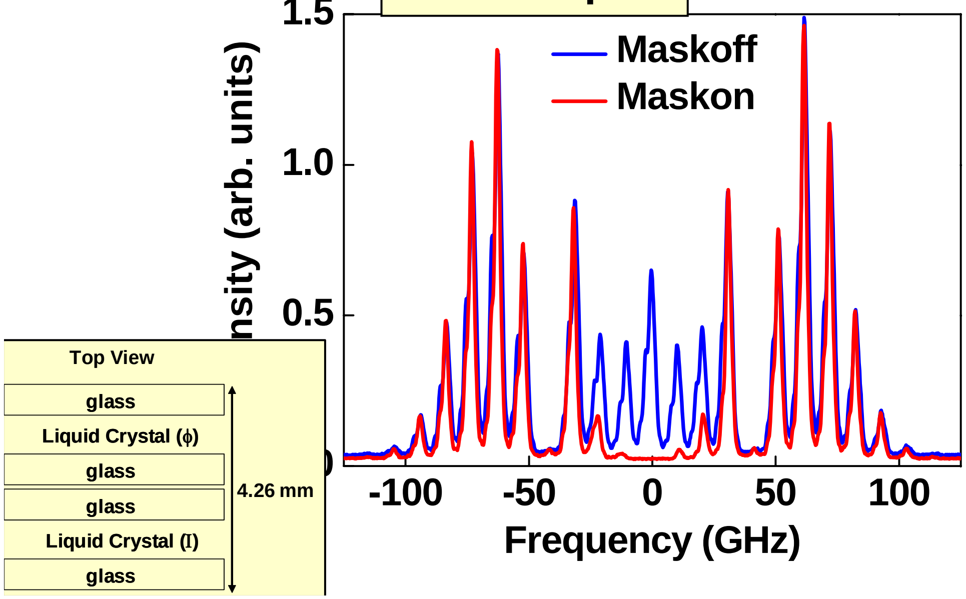
Pulse shaping



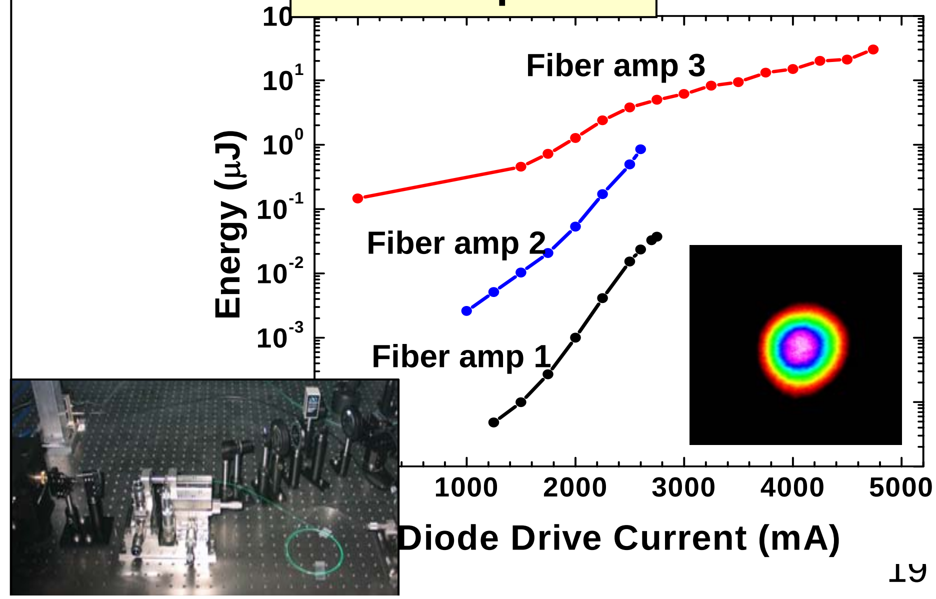
LLE Modulator



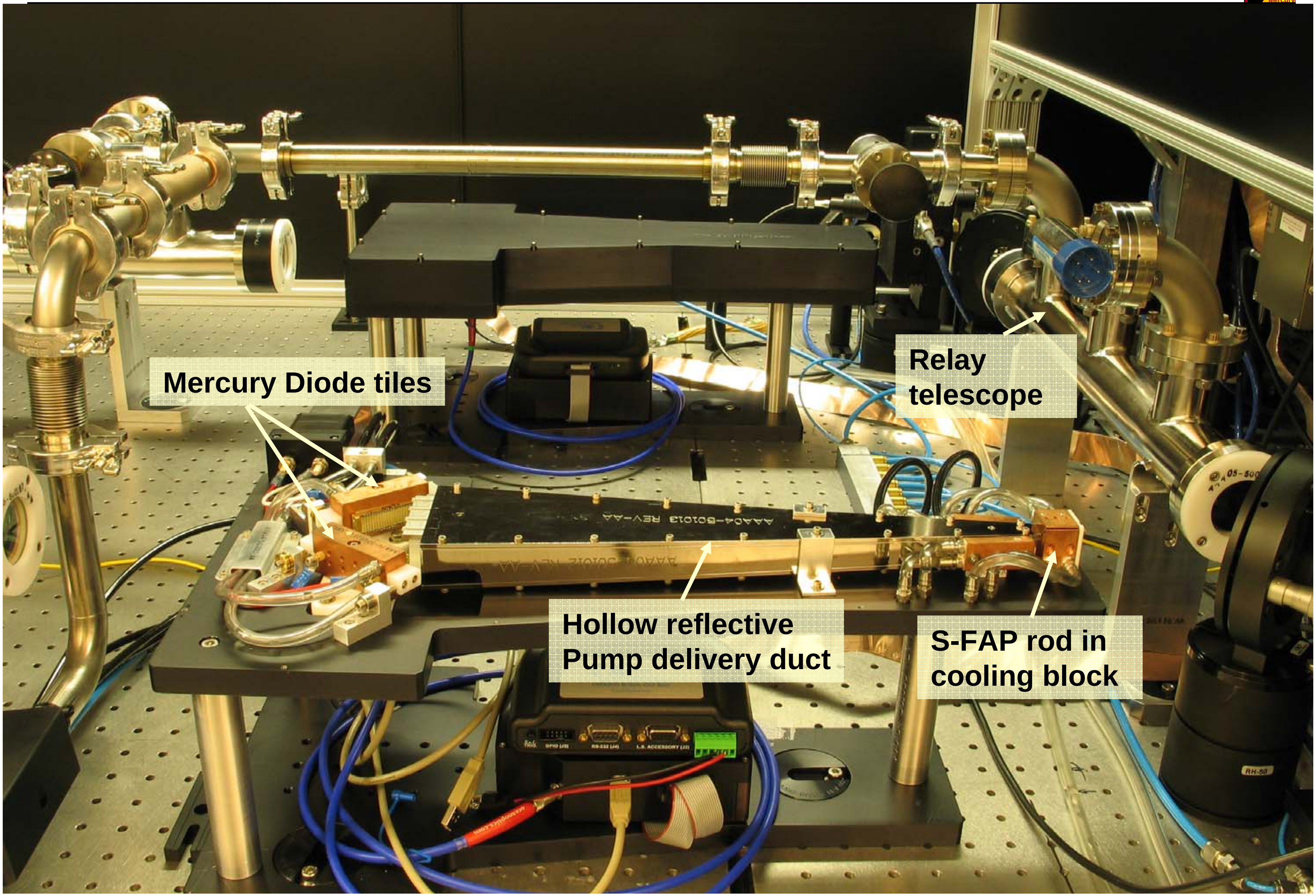
LLE Sculptor



Fiber Amplifiers

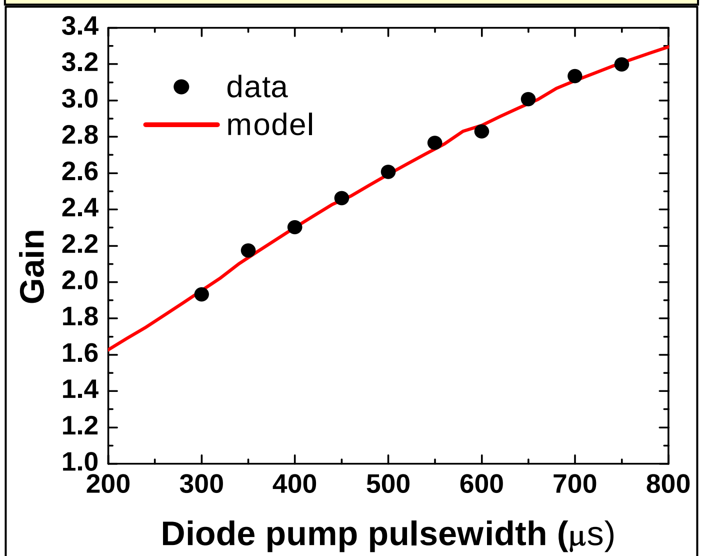


Fiber osc — Temporal shp — Fiber amp — RF bandwidth — Spectral sculpt — Fiber amp — S-FAP Ring

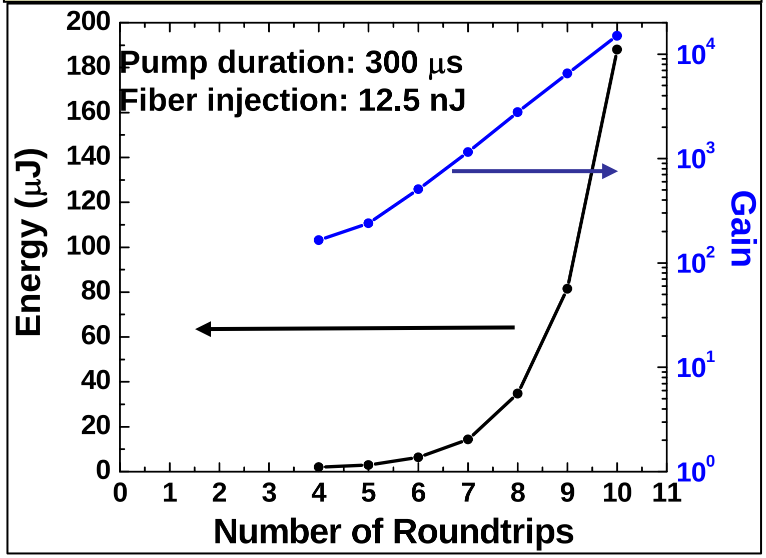


Initial ring amplifier data show the small signal gain matching the model and successful multipass pulsed amplification

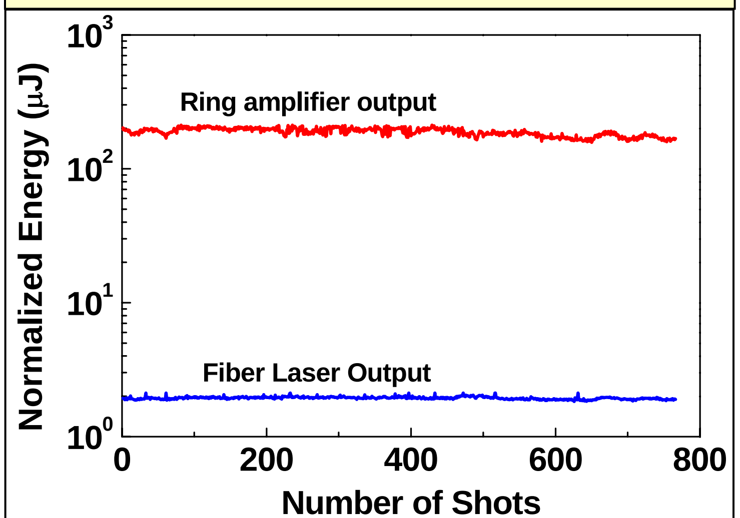
Gain per amplifier



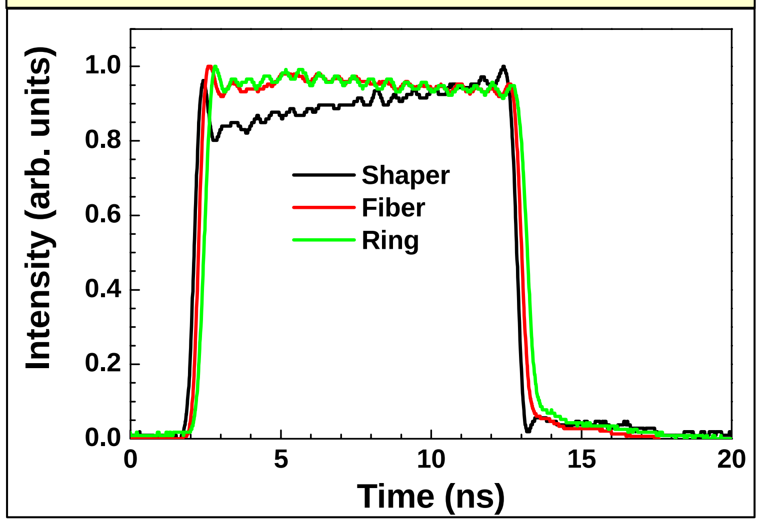
Energetics



Average Power

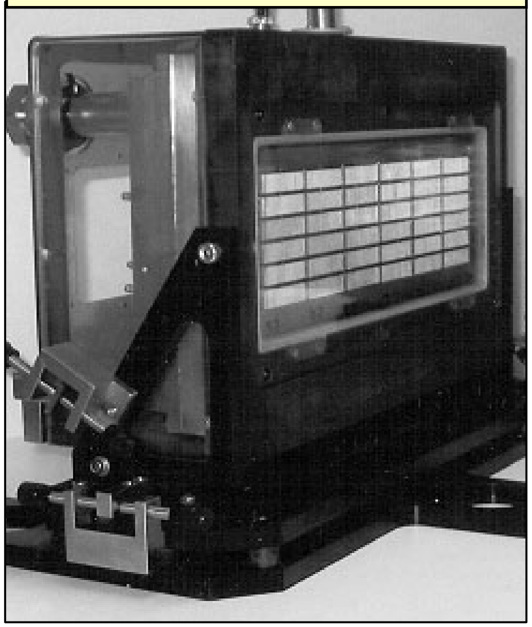


Pulseshaping



A new adaptive optic has been installed

Diode pump arrays



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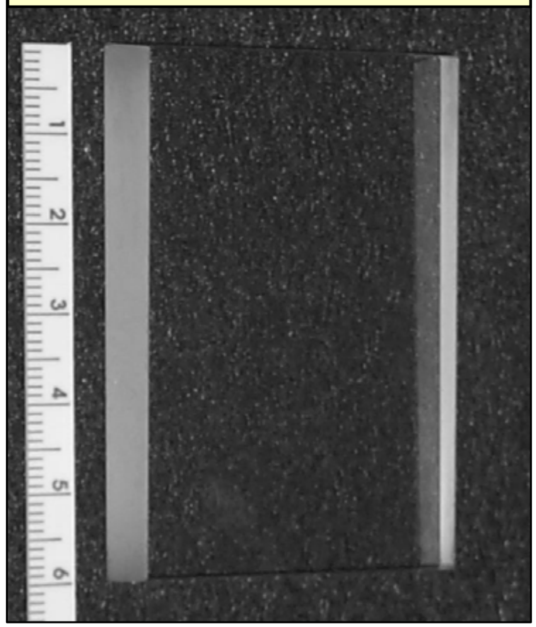

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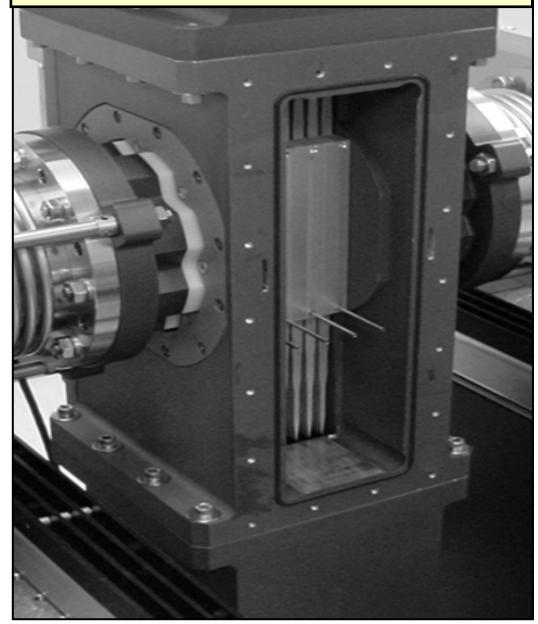

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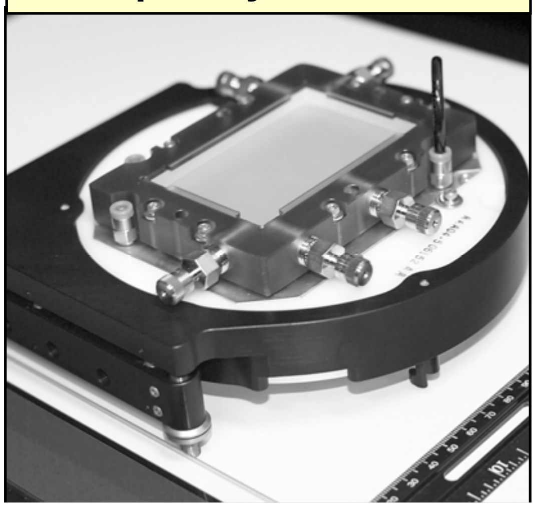

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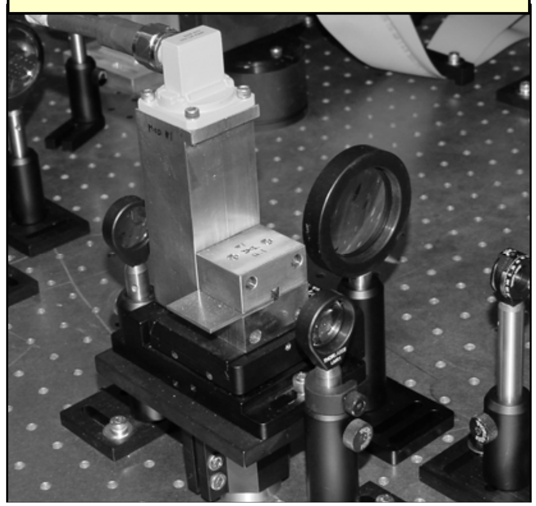
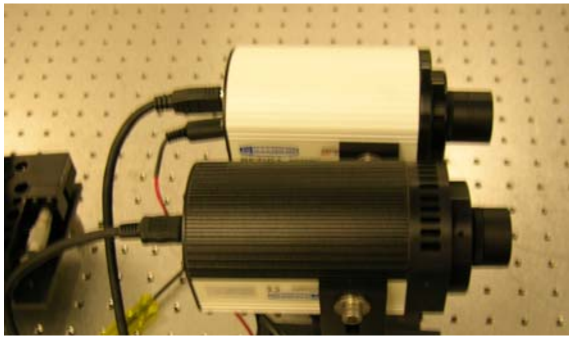


Adaptive Optic

Our adaptive optic system passed initial inspection and tests

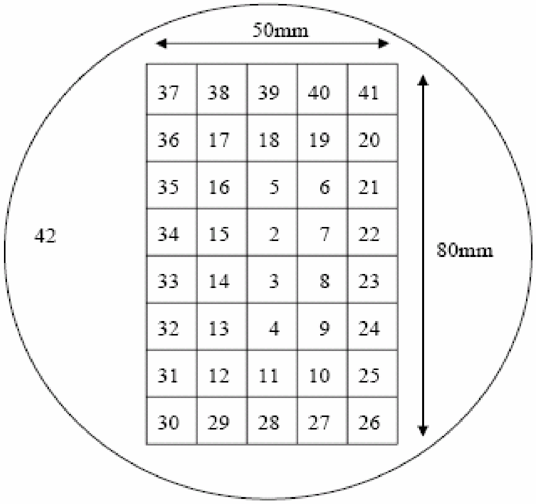
Wavefront Sensor

Uses a four-wave lateral shearing interferometer for high resolution and simple alignment



	Specification	Test Result
Resolution	256x256	300x300
Sensitivity (waves)	0.05	0.05
Dynamic Range (waves)	0.05-150	0.05-150
Repetition rate (Hz)	12	12

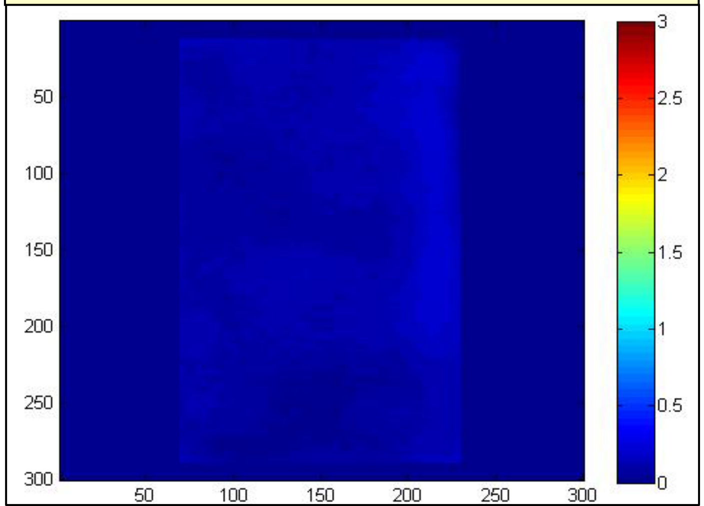
Adaptive Optic



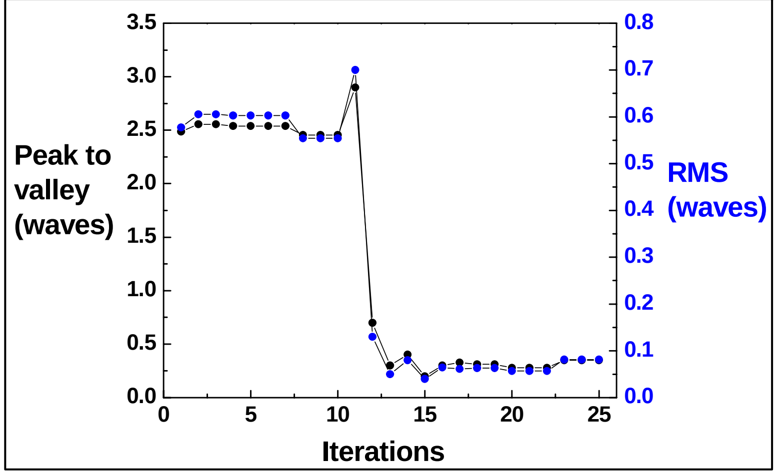
	Spec	Test
Active aperture	45 x 75 mm	OK
Maximum Stroke (w/o defocus)	> 3 waves	OK
Flatness (w/o Defocus)	< 1 wave	0.9 waves
Transmission	< 0.2 %	0.065 %
Damage Threshold	>3 GW/cm^2	3.3 GW/cm^2

A static phase plate was used to test the adaptive optic

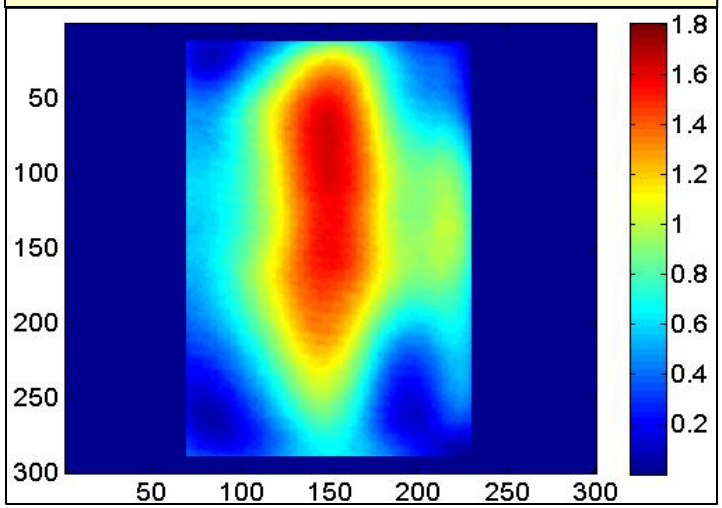
Flatness of mirror alone
PV=0.15, RMS=0.02



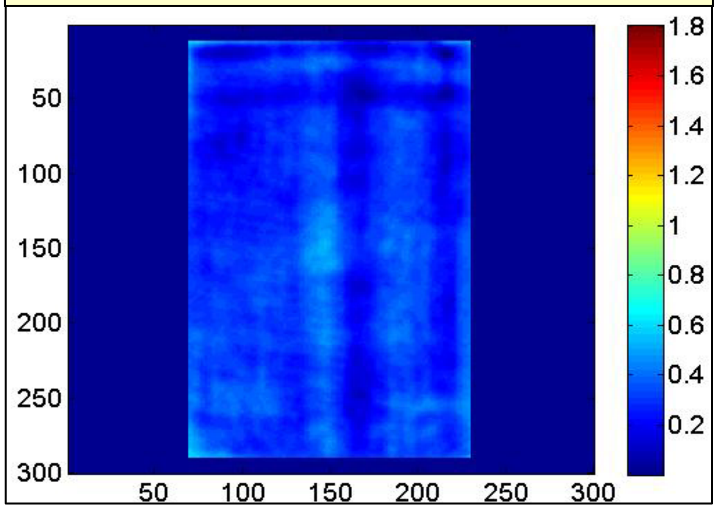
Closed loop operation



Static phase plate
PV=1.65, RMS=0.402



Phase plate correction
PV=0.593, RMS=0.075



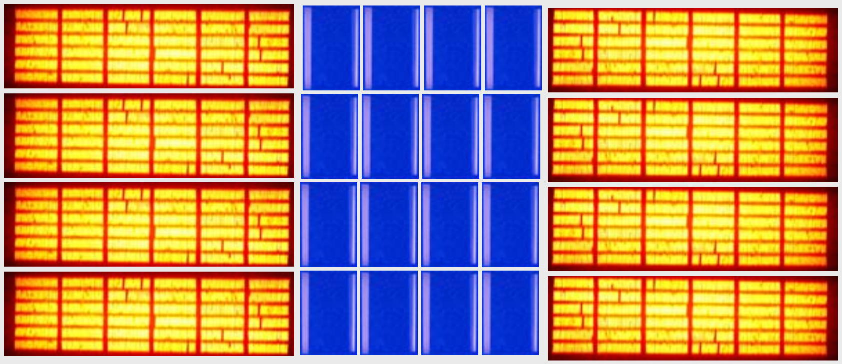
We are successfully meeting our performance goals

Components	Goal	Present	End FY06
Amplifier slabs (4x6 cm)	14 √	14	28
Diode tiles (120 W/bar)	288 √	360	360
Amplifiers	2 √	2	2
- Cooling uniformity (rms)	<1% √	0.12%	0.12%
2ω Conversion crystals	2 √	3	3
3ω Conversion crystals	3	1	3
Wavefront control	DM	Commissioned	Online
Laser Performance			
Energy (J)	100	65	100
Rep-rate (Hz)	10 √	10	10
Efficiency (%)	10	6.5	10
Diode reliability (shots)	10^8 √	10^9	10^9
Beam quality (xDL)	5	4 @ 65J (80%)	5
Pulse-shaping (ns)	3-10 √	3-15	3-15
Bandwidth (GHz @ 1ω)	>150	Offline	250 GHz
Conversion	2ω/3ω	2ω	2ω/3ω

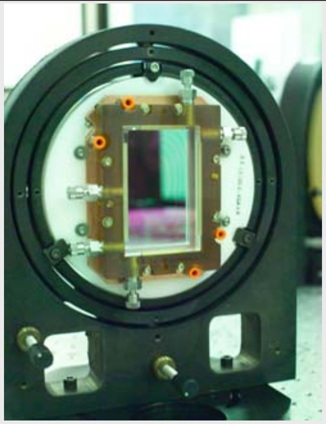
√ Completed   [green] On schedule

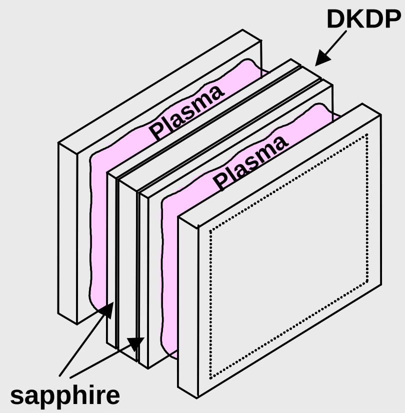
The DPSSL approach will begin to develop multi-kJ scale components in FY06

Beam Bundling

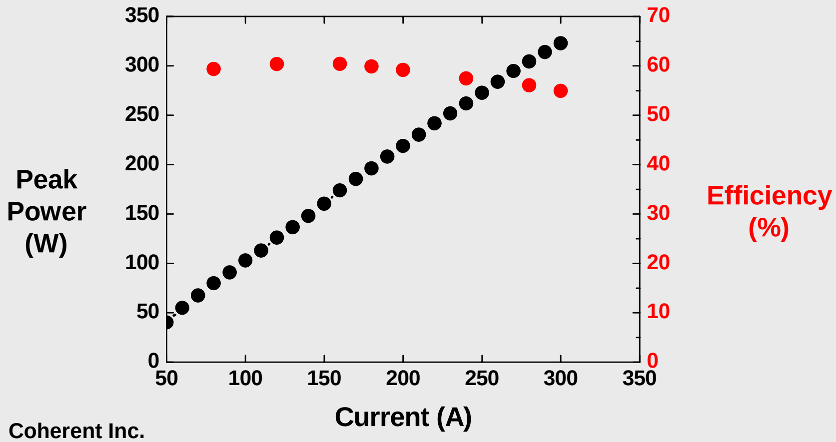


Optical Switch





High Performance Diodes



Coherent Inc.

Large Scale Growth

15 cm Nd:GGG	40 cm CaF_2

Northrop Grumman

Schott Technologies

Summary

- **Project Overview**
  - International/National DPSSL Programs are pushing technology envelopes

- **System Performance**
  - Mercury Laser performance goals are on track
    - 325 W average power at 14 ns for > 10^3 shots (65 J at 5 Hz)
    - Beam quality at 80% of energy in a 4X diffraction limited spot

- **Component Performance**
  - Pump diode arrays (Commercial prototypes meet specs)
  - Crystalline gain media (23 spare slabs in queue)
  - Gas cooled amplifiers (Thermal wavefront agrees with model)
  - Frequency conversion (YCOB advanced material in production, scalable chilled plate prototype demonstrated)
  - Front end (90% complete)
  - Adaptive optics (Mirror Commissioned)

- **Next Generation Design Considerations**
  - System engineering with statistics in mind
  - Out-of-the box thinking to push efficiencies
  - Leveraging NIF engineering
  - Leveraging subscale facilities for component development/chamber materials/chamber environment

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Zygo