LLNL-PRES-408165

Status of the E23 Project: A High Average Power Femto-Petawatt Laser for High Intensity Applications

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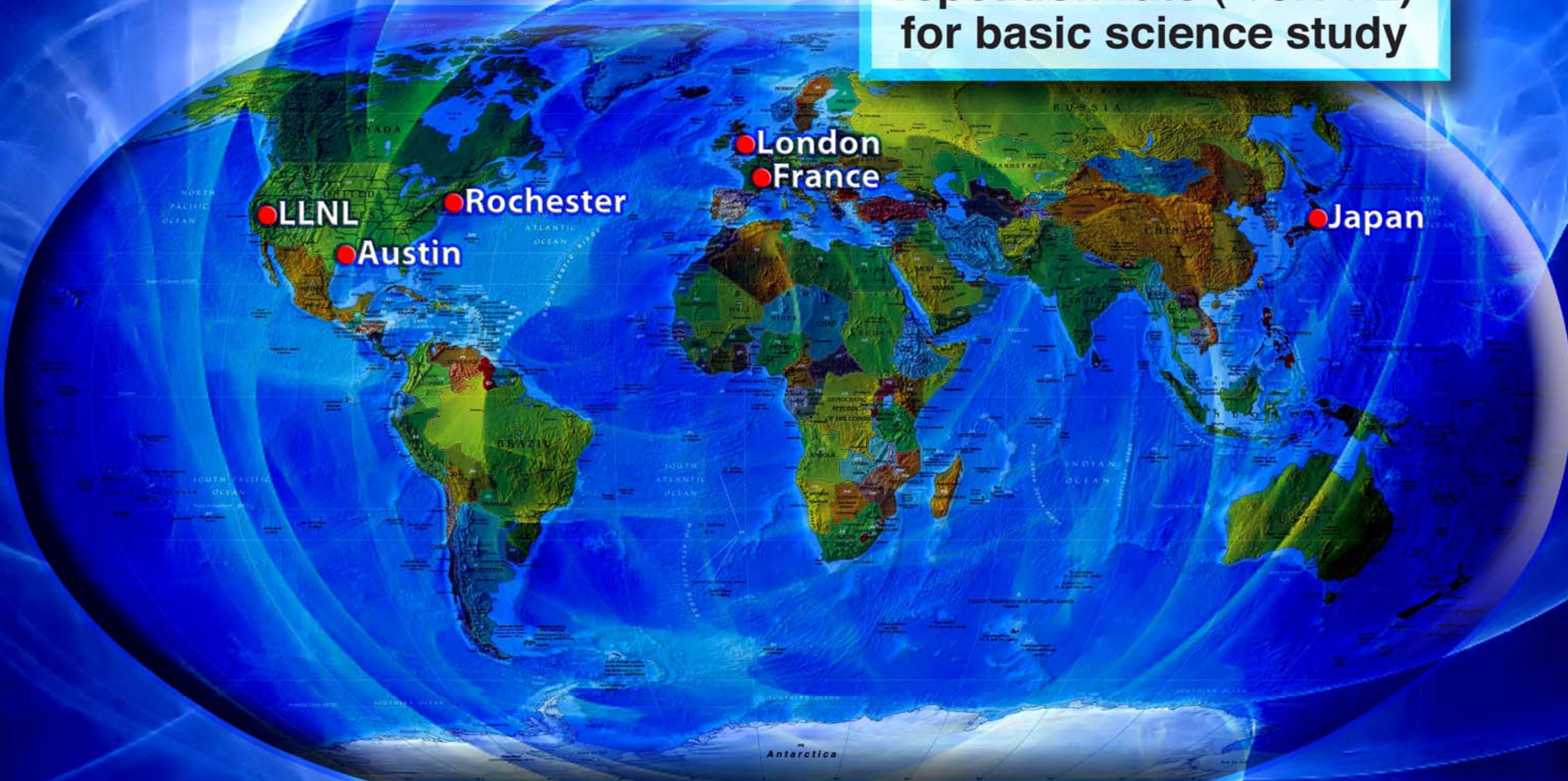
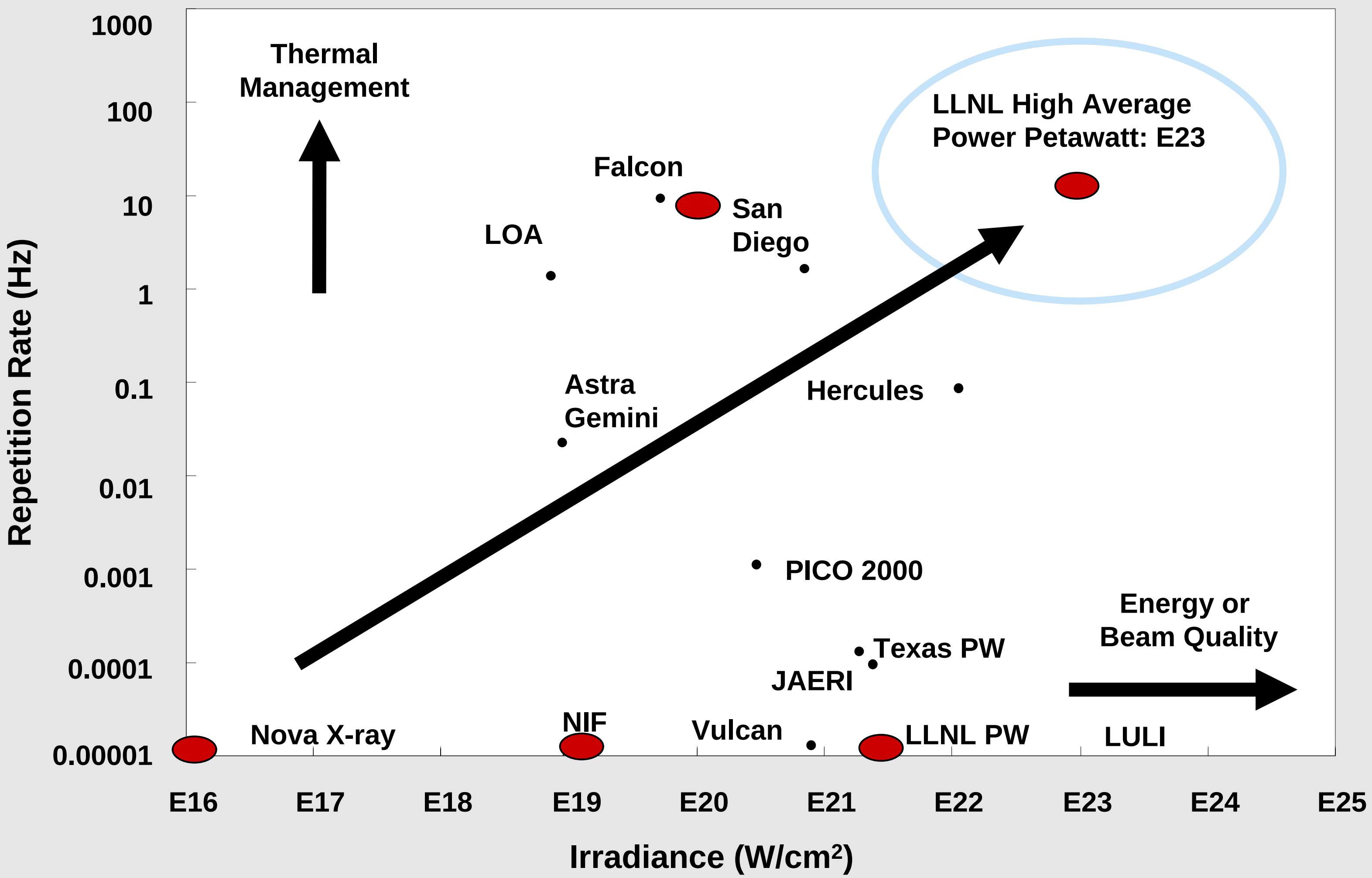
Worldwide petawatt laser sources are typically low repetition rate (< 0.1 Hz) for basic science study



These sources achieve focused irradiance of ~ 10^{21} W/cm^2

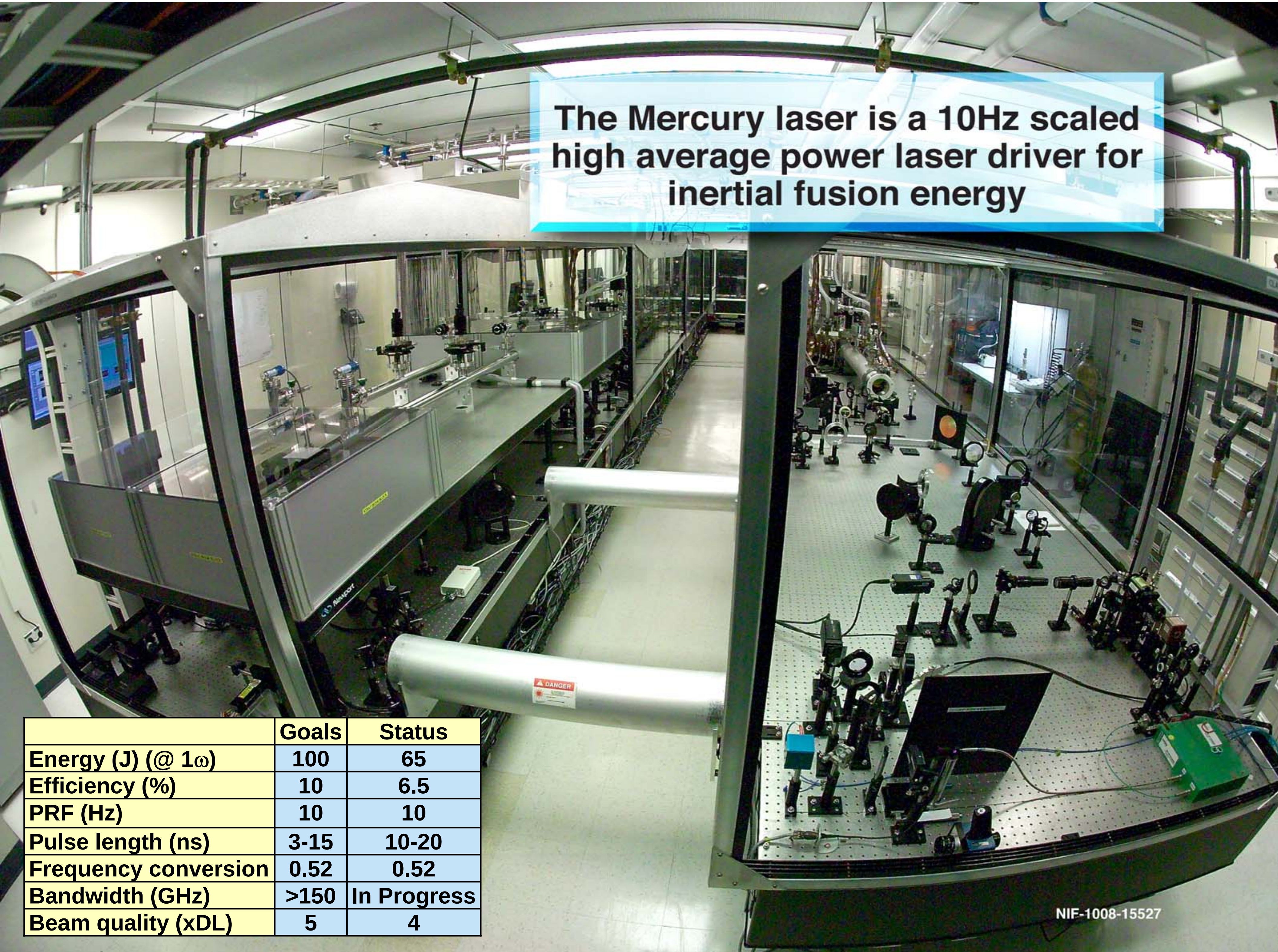
Worldwide high irradiance facilities show a trend toward higher repetition rate and higher intensity

Sampling of facility capabilities around the world



We will use our 10 Hz feedback to create focused irradiance up to 10^{23} W/cm^2

The Mercury laser is a 10Hz scaled high average power laser driver for inertial fusion energy



	Goals	Status
Energy (J) (@ 1ω)	100	65
Efficiency (%)	10	6.5
PRF (Hz)	10	10
Pulse length (ns)	3-15	10-20
Frequency conversion	0.52	0.52
Bandwidth (GHz)	>150	In Progress
Beam quality (xDL)	5	4

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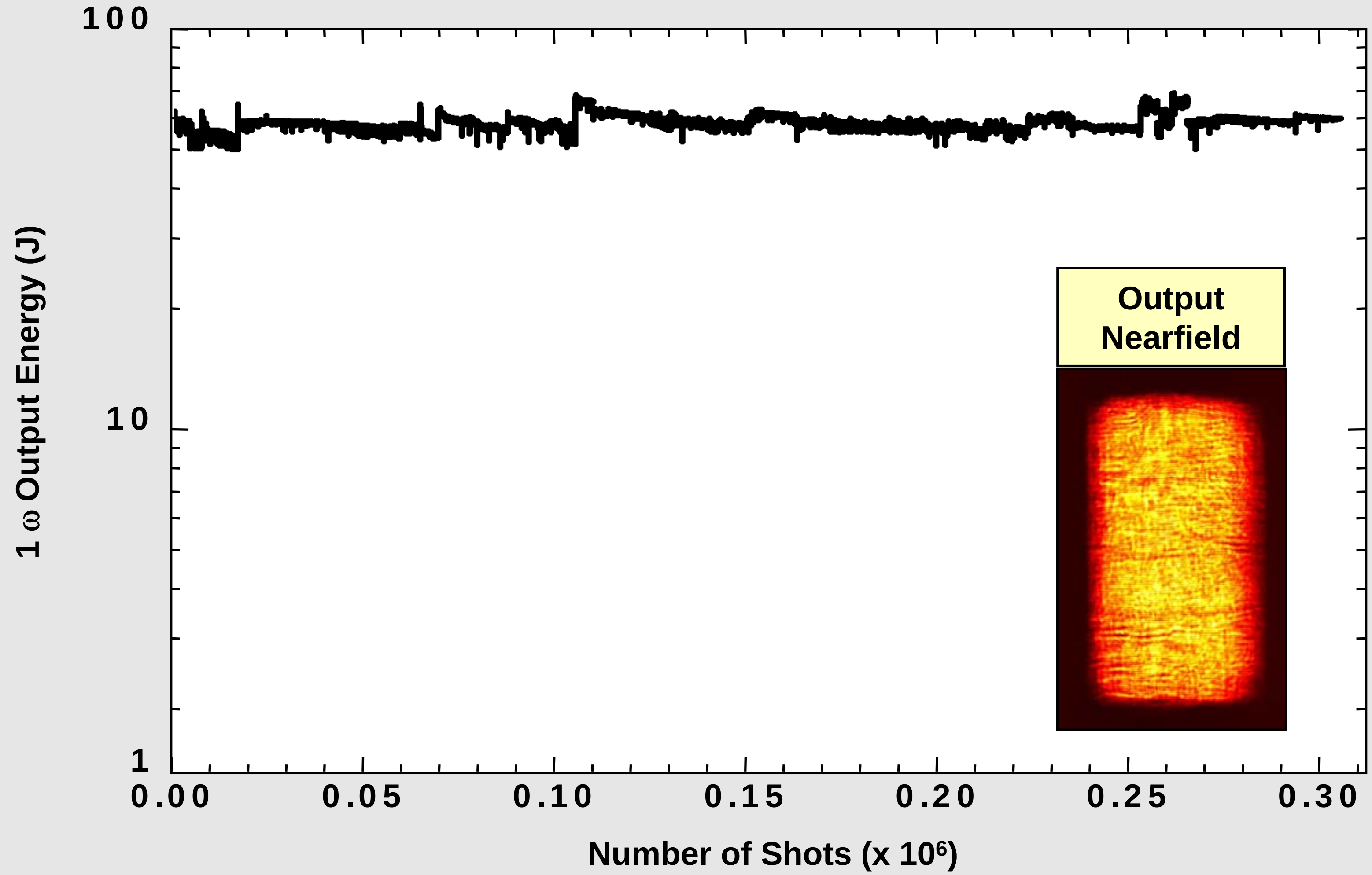
Mercury has operated above 50 Joules for over 0.3 million shots at 10 shots per second

Mercury shot histogram of consecutive 0.5 - 2 hr operations

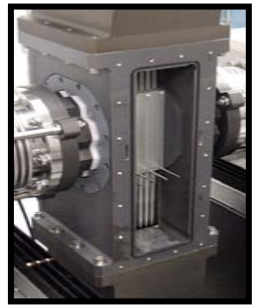


The advanced technologies on Mercury can be applied to power scaling of Ti:sapphire systems

PHOTON SCIENCE & APPLICATIONS

100-kW Diode Arrays

High-Speed Helium Gas Cooling

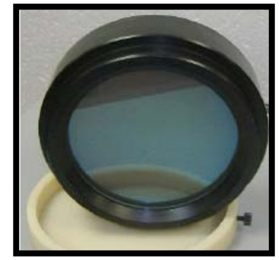


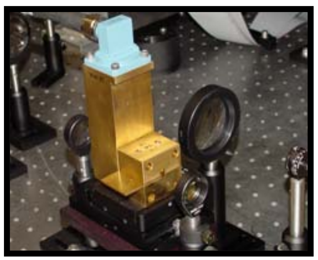
Broadband Front End With Spectral And Temporal Sculpting

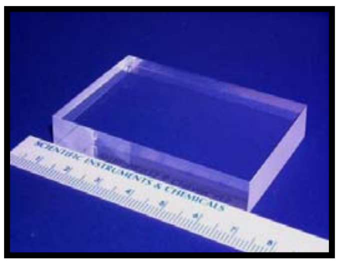
Yb:S-FAP Gain Media

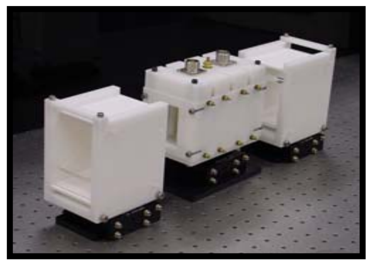
Thermal Birefringence Compensated Pockels Cell

Bi-morph Adaptive Optic And Close Loop Control

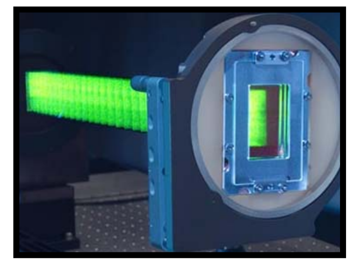








YCOB High Average Power Frequency Conversion

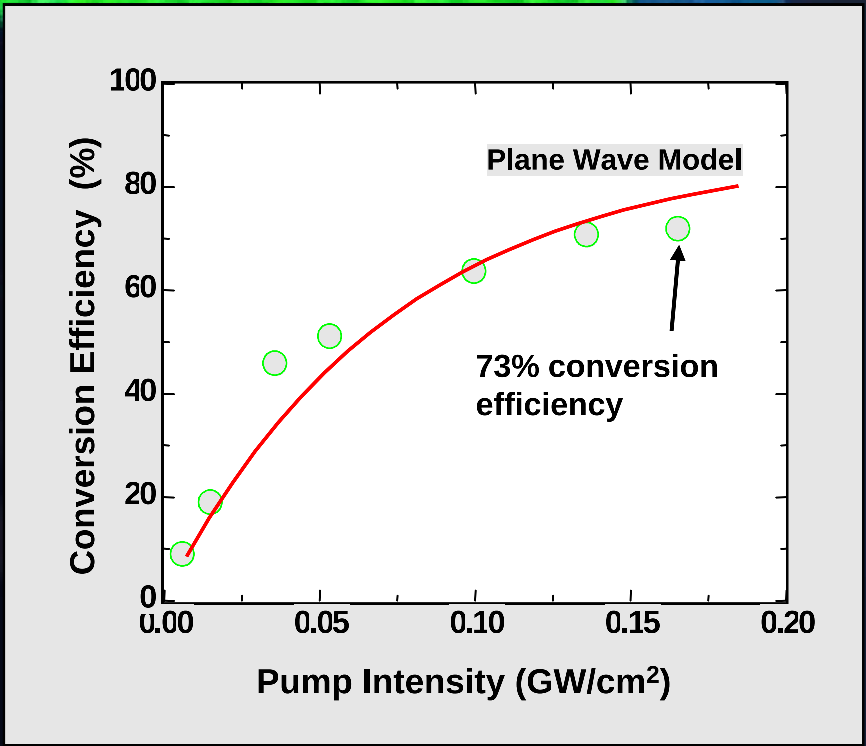


- Image relayed, angular multiplexed architecture
- High speed helium gas cooling (scalable aperture)
- MRF correction of wavefront
- High average power edge cladding
- Adaptive optics

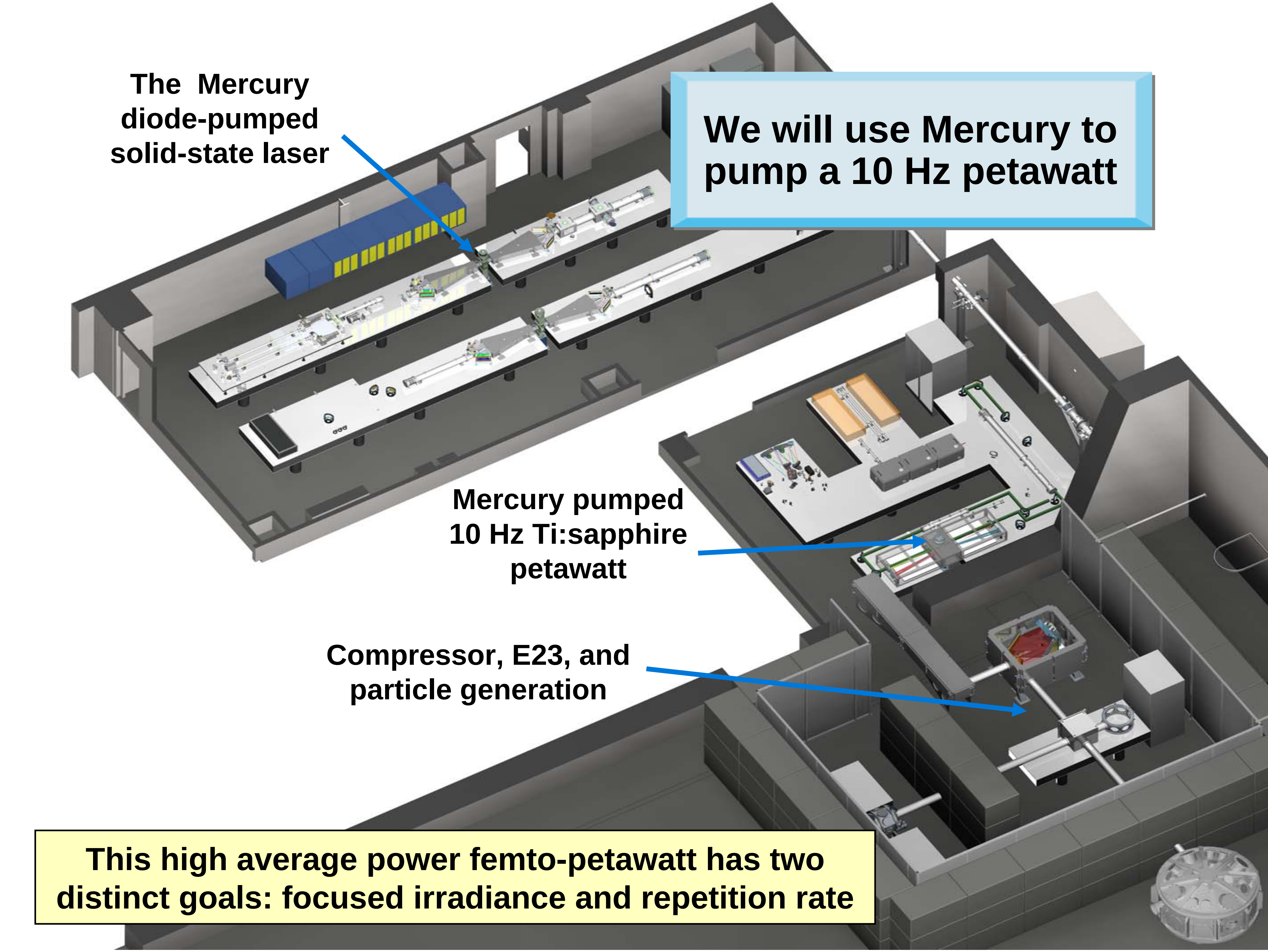
Thin Fresnel Final Optic (TBD)

Chamber (TBD)

Growth of YCOB enabled straightforward implementation of high average power second harmonic generation



Conversion up to 317 W average power (31.7 J/shot) at 523 nm achieved

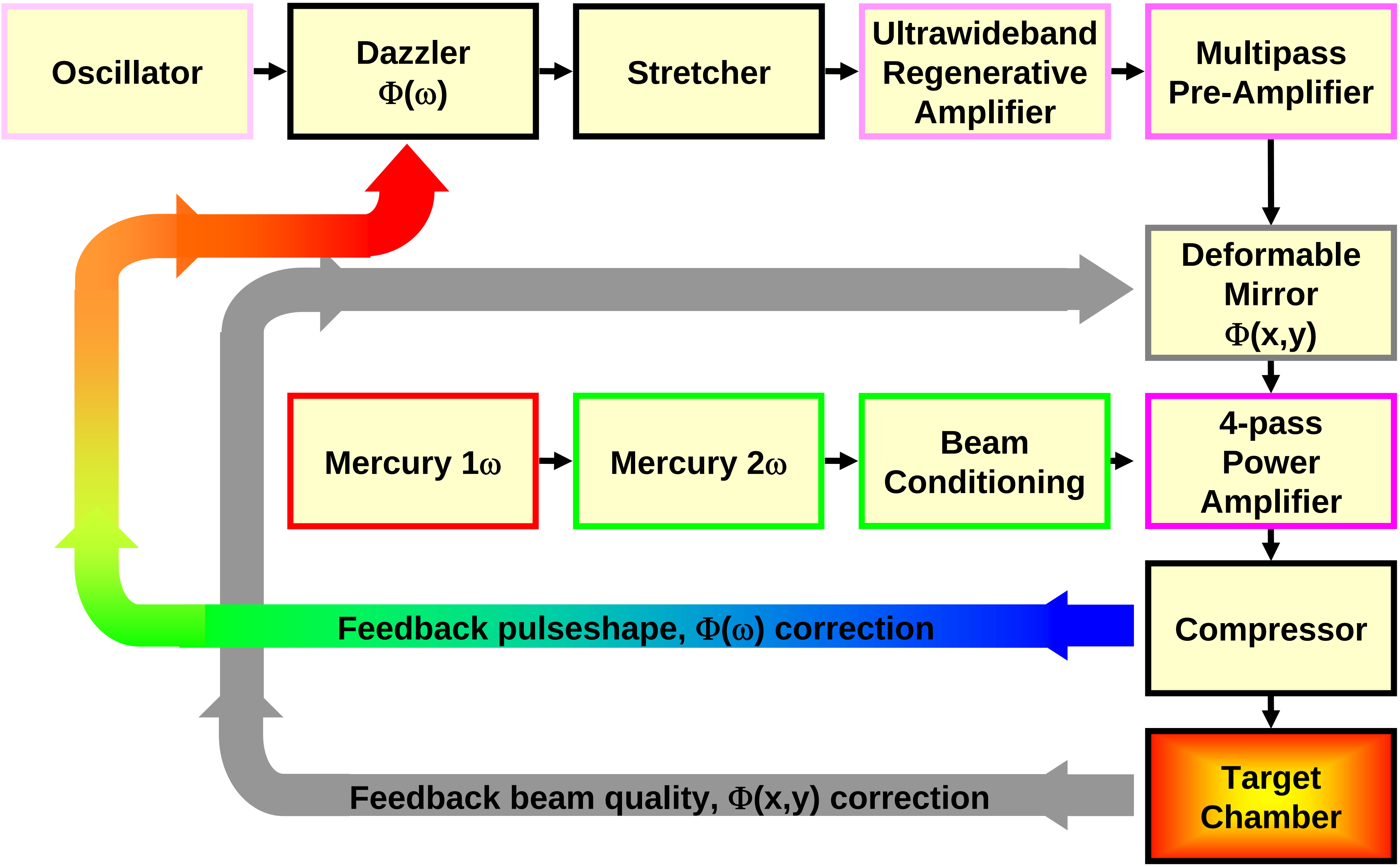

The Mercury diode-pumped solid-state laser
We will use Mercury to pump a 10 Hz petawatt
Mercury pumped 10 Hz Ti:sapphire petawatt
Compressor, E23, and particle generation
This high average power femto-petawatt has two distinct goals: focused irradiance and repetition rate

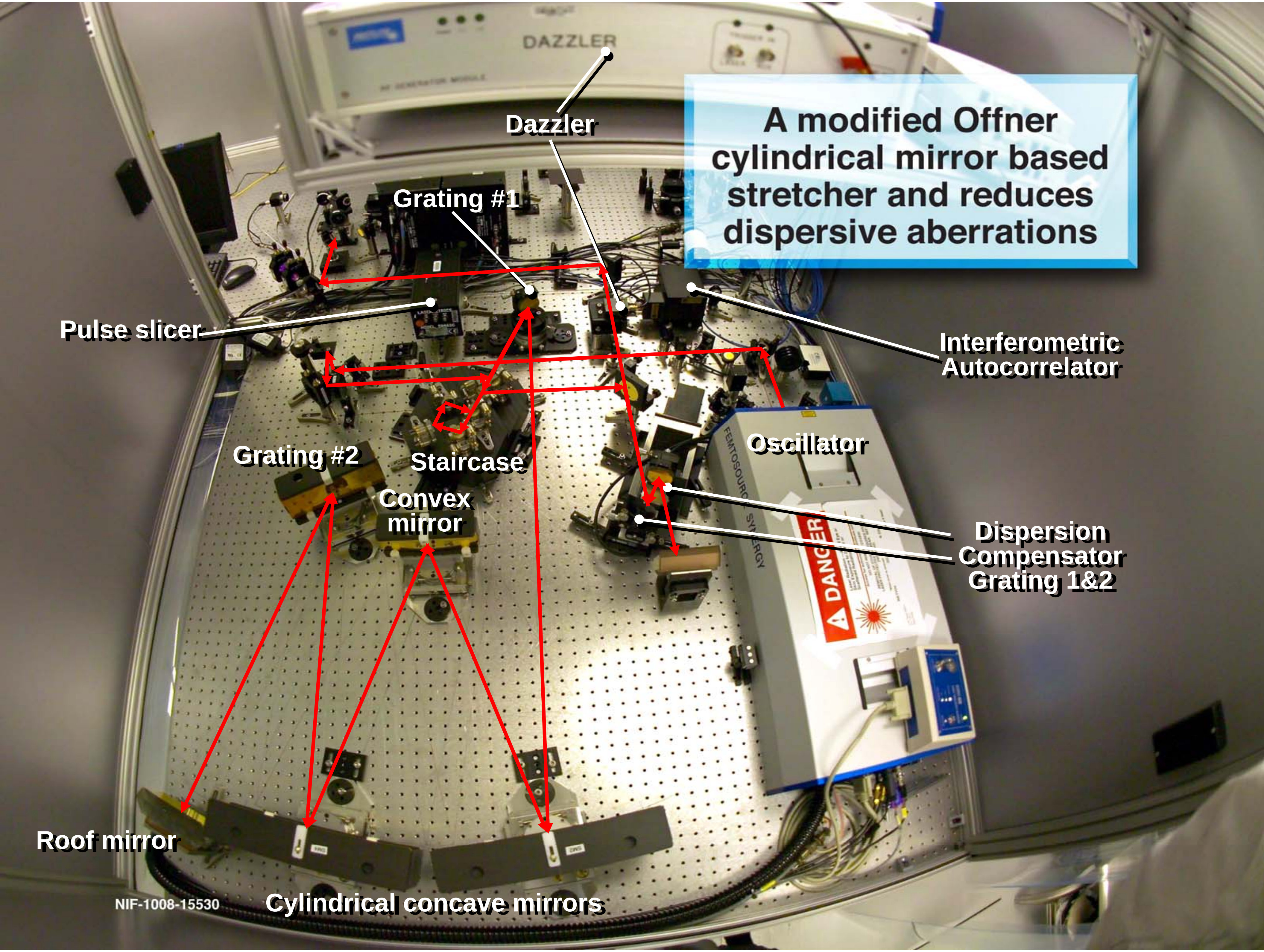
15 J Petawatt capability requires 90 Joule 1w output of the Mercury pump-laser

Loss Factor	Efficiency Low value	Efficiency Mid value	Efficiency High value	Energy (J) Low value	Energy (J) Mid value	Energy (J) High value
Parabolic reflector	0.95	0.97	0.98	9.4	15.2	18.8
Compressor	0.6	0.71	0.78	9.7	15.7	19.4
Chirped Pulse Transport	0.95	0.96	0.97	14.4	22.0	26.7
Energy Extraction	0.75	0.8	0.85	15.0	23.0	27.9
Energy Storage	0.4	0.55	0.6	19.0	28.8	34.7
Absorbed Pump Energy	0.92	0.93	0.94	41.6	52.3	61.9
2ω Transport	0.85	0.93	0.95	44.7	56.2	66.5
Harmonic Conversion	0.6	0.7	0.8	49.3	60.5	71.5
1ω transport	0.92	0.96	0.98	76.1	86.4	96.2
Mercury 1ω output				80	90	100

Expected energy on target is 15.2 J + 3.6 J / - 5.8 J (rms uncertainties)

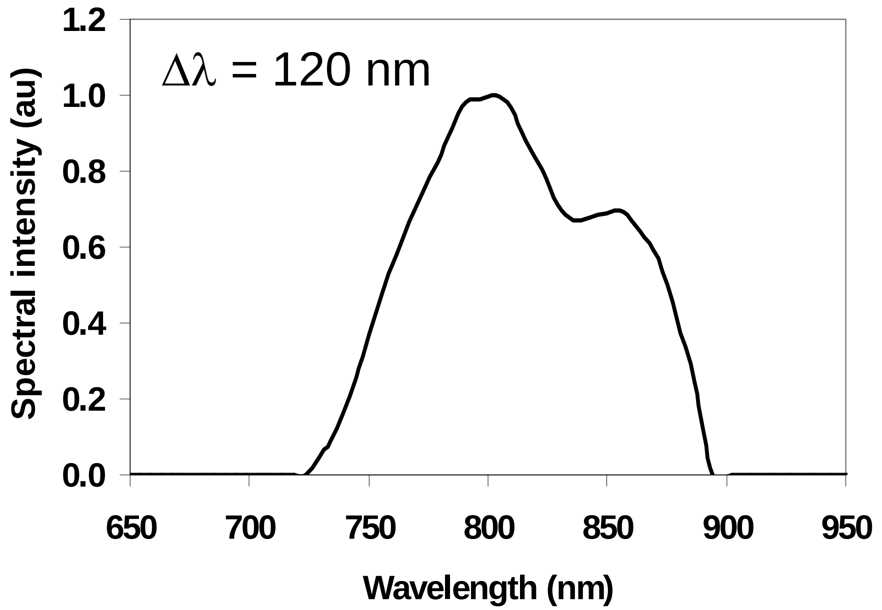
10 Hz operation enables real time feedback for dispersive and spatial control of petawatt pulses



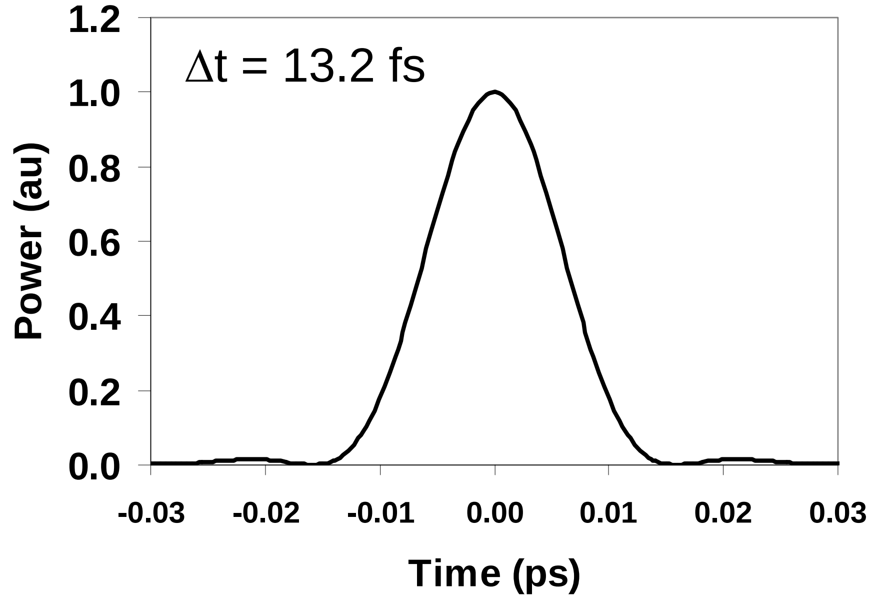

DAZZLER
A modified Offner cylindrical mirror based stretcher and reduces dispersive aberrations
Dazzler
Grating #1
Pulse slicer
Interferometric Autocorrelator
Oscillator
Grating #2
Staircase
Convex mirror
FEMTOSOURCE SYNERGY
DANGER
Dispersion Compensator Grating 1&2
Roof mirror
Cylindrical concave mirrors
NIF-1008-15530

An end to end energetics model indicates we will maintain sufficient bandwidth to compress to 13 fs

E23 predicted output spectrum



Predicted transform-limited pulsewidth



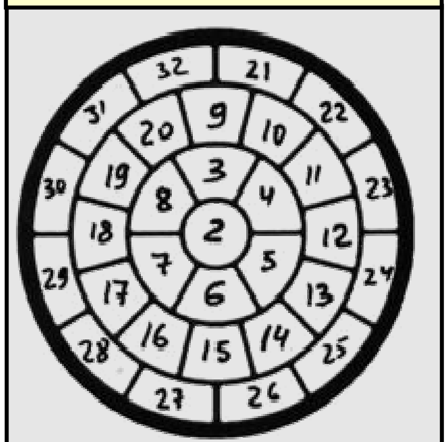
Spectral phase correction will be accomplished using a combination of the dispersion compensator, static correctors and a Dazzler

Our adaptive optics system will correct the low order wavefront aberration

Bi-Morph Deformable Mirror

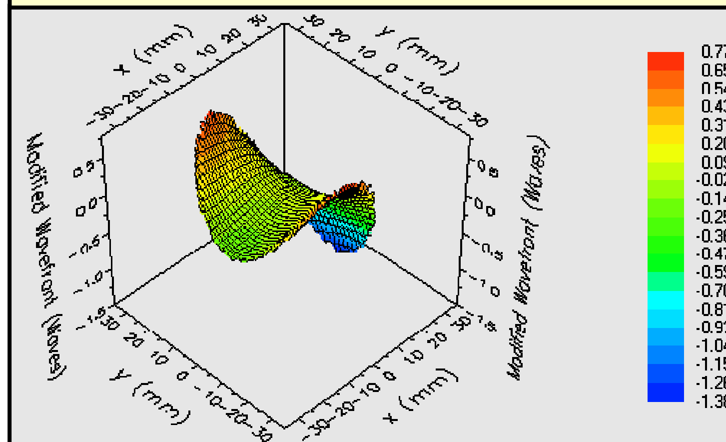
- **Paired with 10 Hz Phasics wavefront sensor**
- **Tested in Mercury**

Actuator Configuration



- **Large single actuator corrects power (20 waves)**
- **30 small actuators (5 waves stroke)**

Induced static wavefront due to the power amplifier

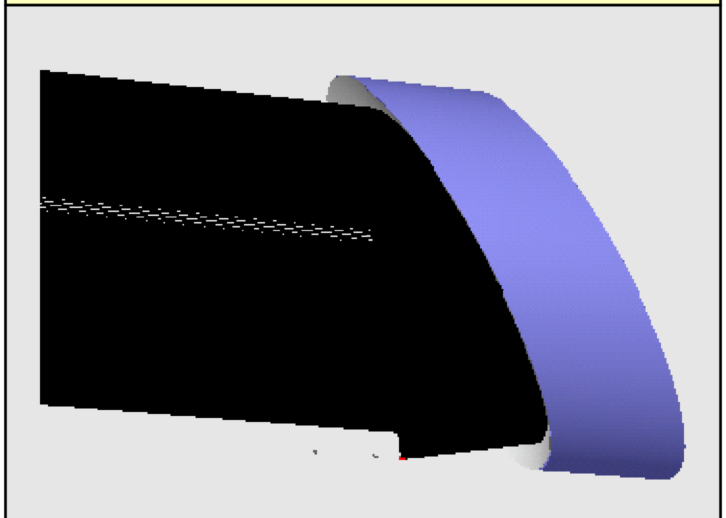


- **Peak to valley, 2.14 waves**
- **RMS, 0.36 waves**
- **Ti:sapphire static MRF corrected**
- **Thermal wavefront 11 waves of power, cavity corrected**

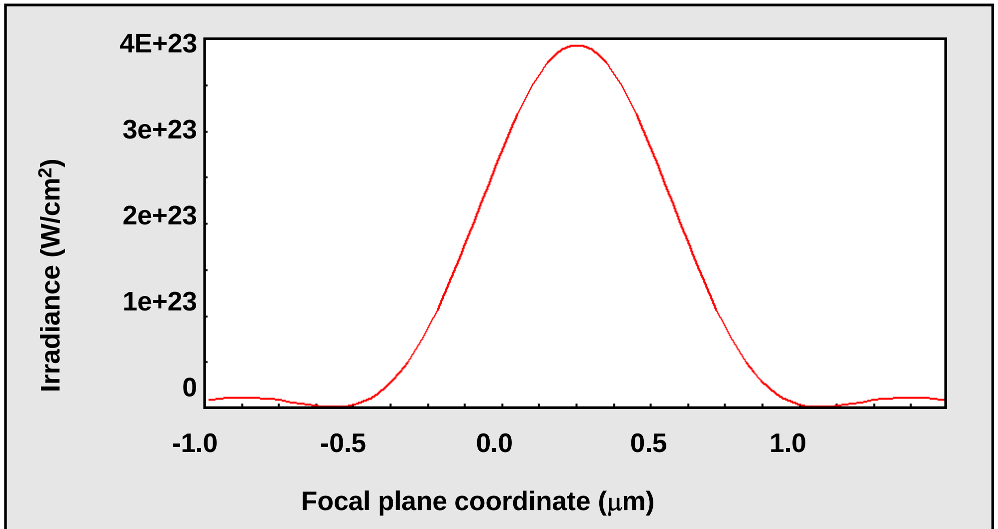
Magneto Rheological Finishing (MRF) or deterministic polishing will be used to correct for high order abberations in the Ti:sapphire and integrated system

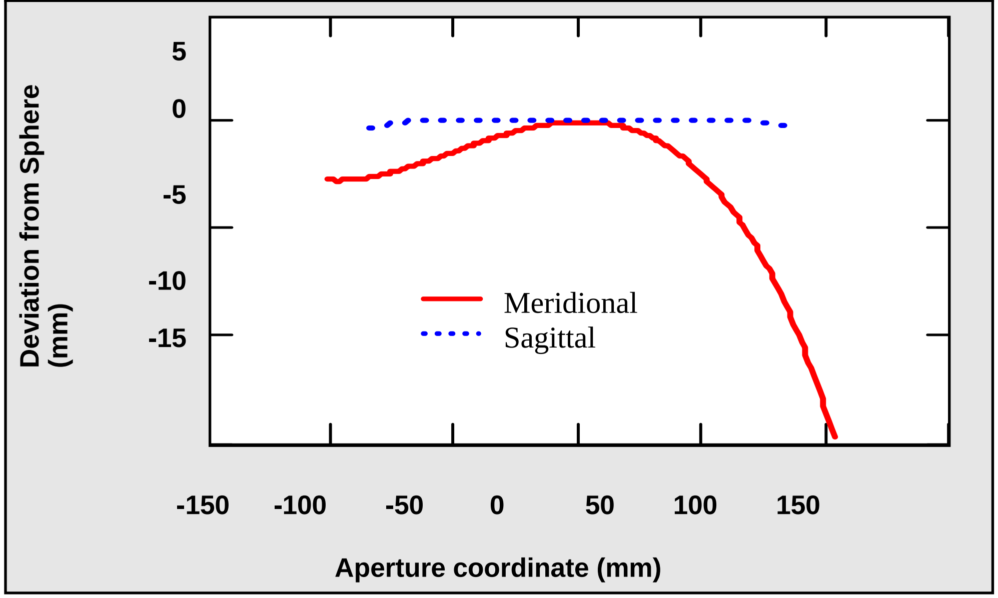
An off axis parabola with a NA = 0.7 (F# ~ 0.5) could focus the output to nearly 4 x 10^{23} W/cm^2

Ray trace model of parabola



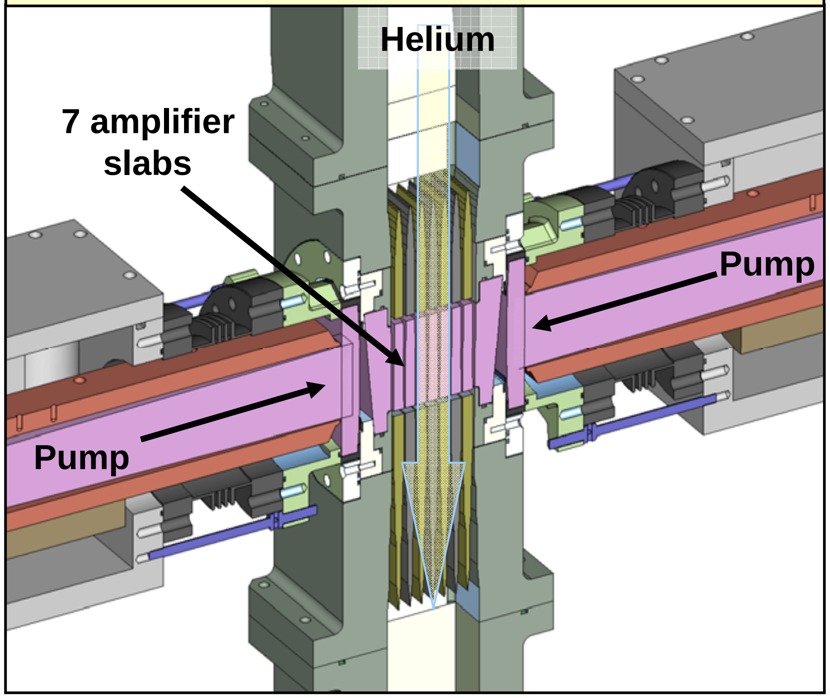
- **The optic is manufacturable using conventional techniques**
- **The surface deviation from a sphere is < 15 mm**



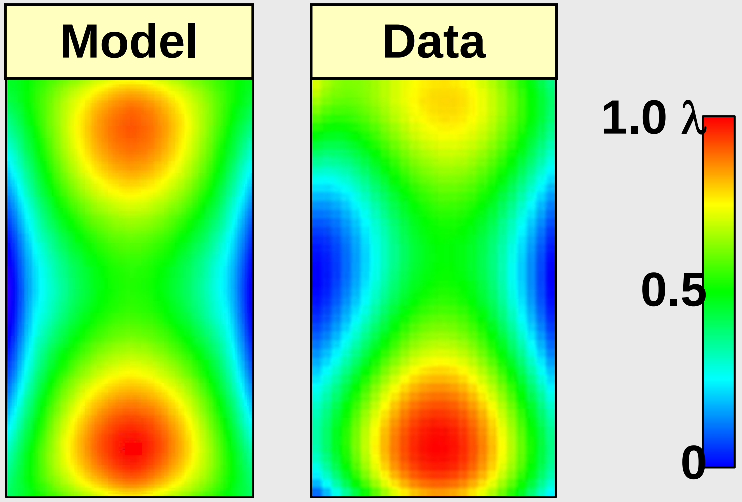


The thermal model for the gas-cooled amplifier in the Mercury laser has been benchmarked

Mach 0.1 helium gas cooling



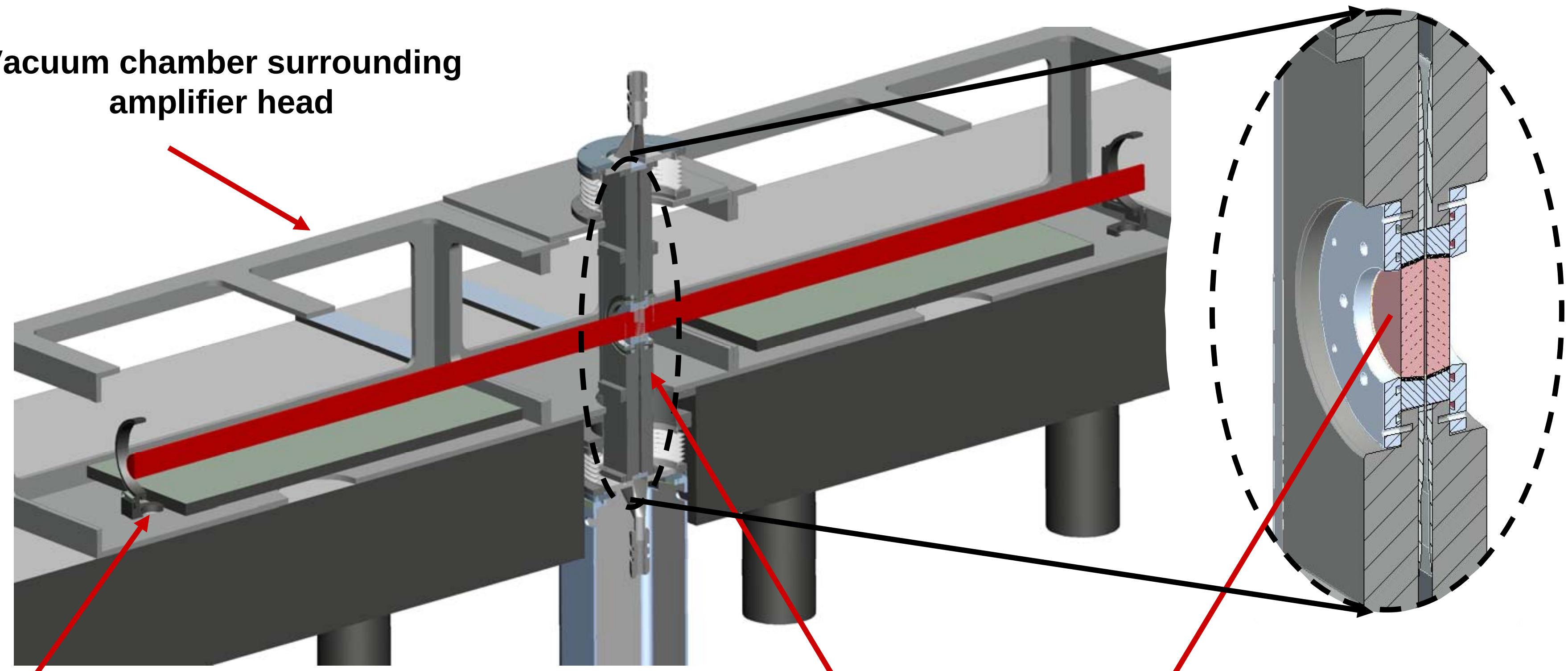
Amplifier Thermal Wavefront



The benchmarked model enables predictive capability for advanced designs

The helium gas-cooled Ti:Sapphire amplifier head is embedded in a 4-pass image-relay cavity

Vacuum chamber surrounding amplifier head



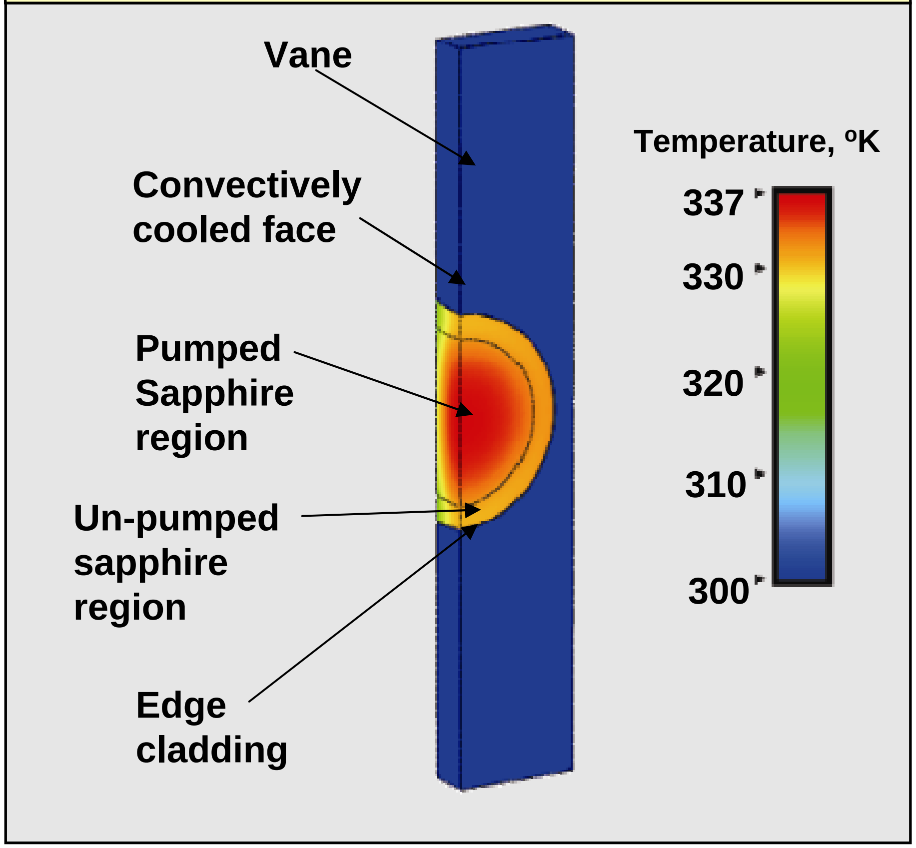
Relay imaging used to minimize wavefront distortions and amplitude modulation

Gas-cooled amplifier head design based on Mercury

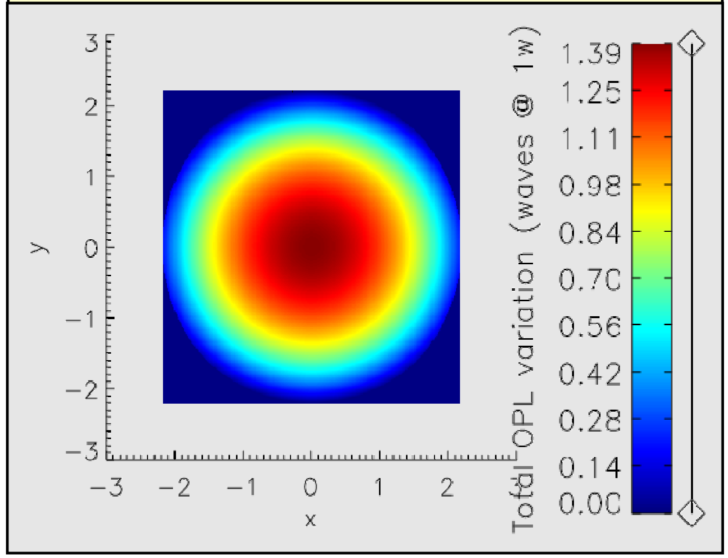
The scalable average power and high beam quality capabilities of this design are new contributions to the field

The thermally induced wavefront distortion in the Ti:sapphire will be almost entirely power (focus)

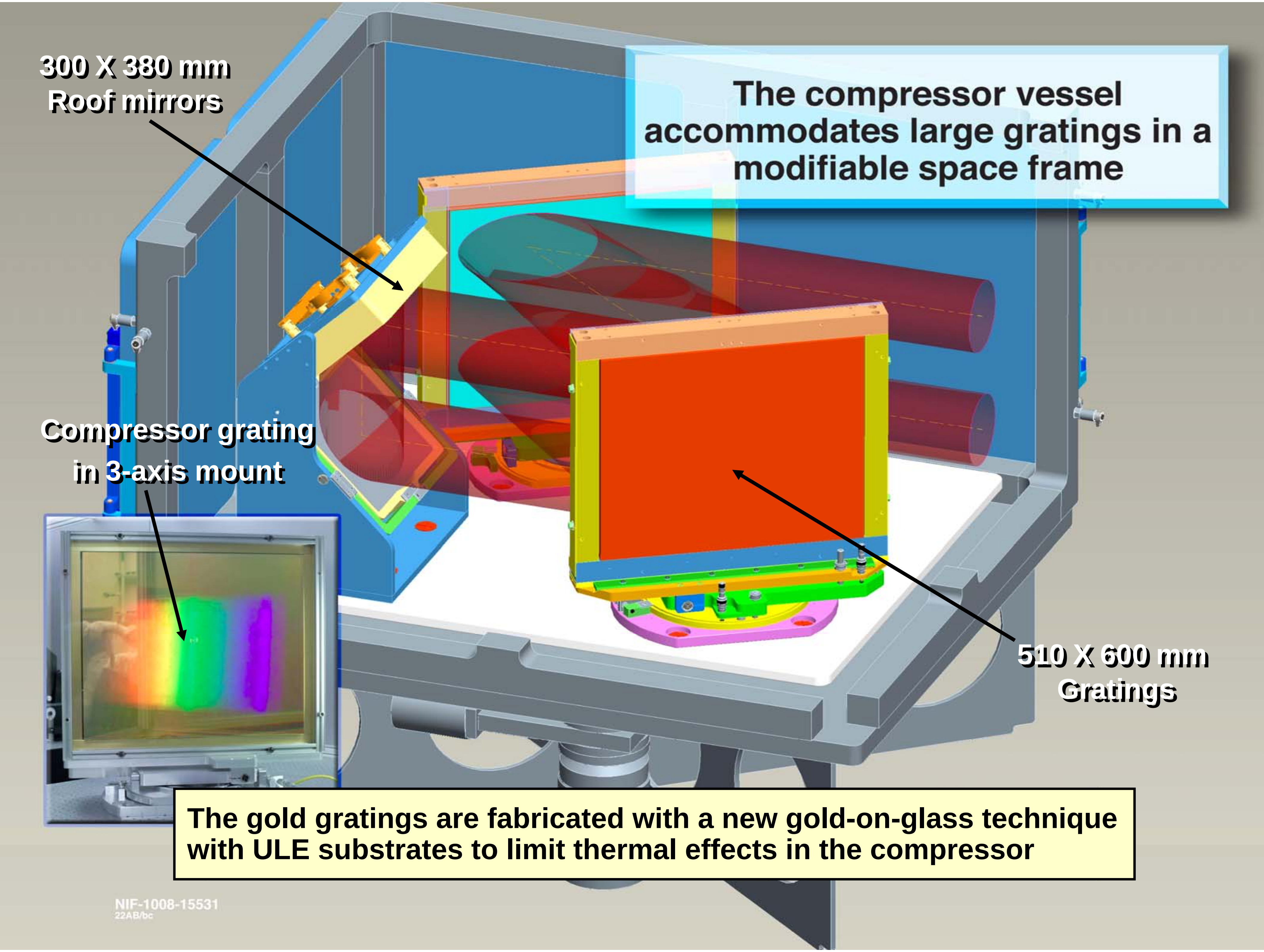
Half geometry showing the temperature distribution for 70 J pump energy



Thermally induced wavefront distortion of the Ti:sapphire



Power correction can be achieved by adjusting the beam transport optics or the deformable mirror


300 X 380 mm
Roof mirrors
The compressor vessel accommodates large gratings in a modifiable space frame
Compressor grating
in 3-axis mount
510 X 600 mm
Gratings
The gold gratings are fabricated with a new gold-on-glass technique with ULE substrates to limit thermal effects in the compressor
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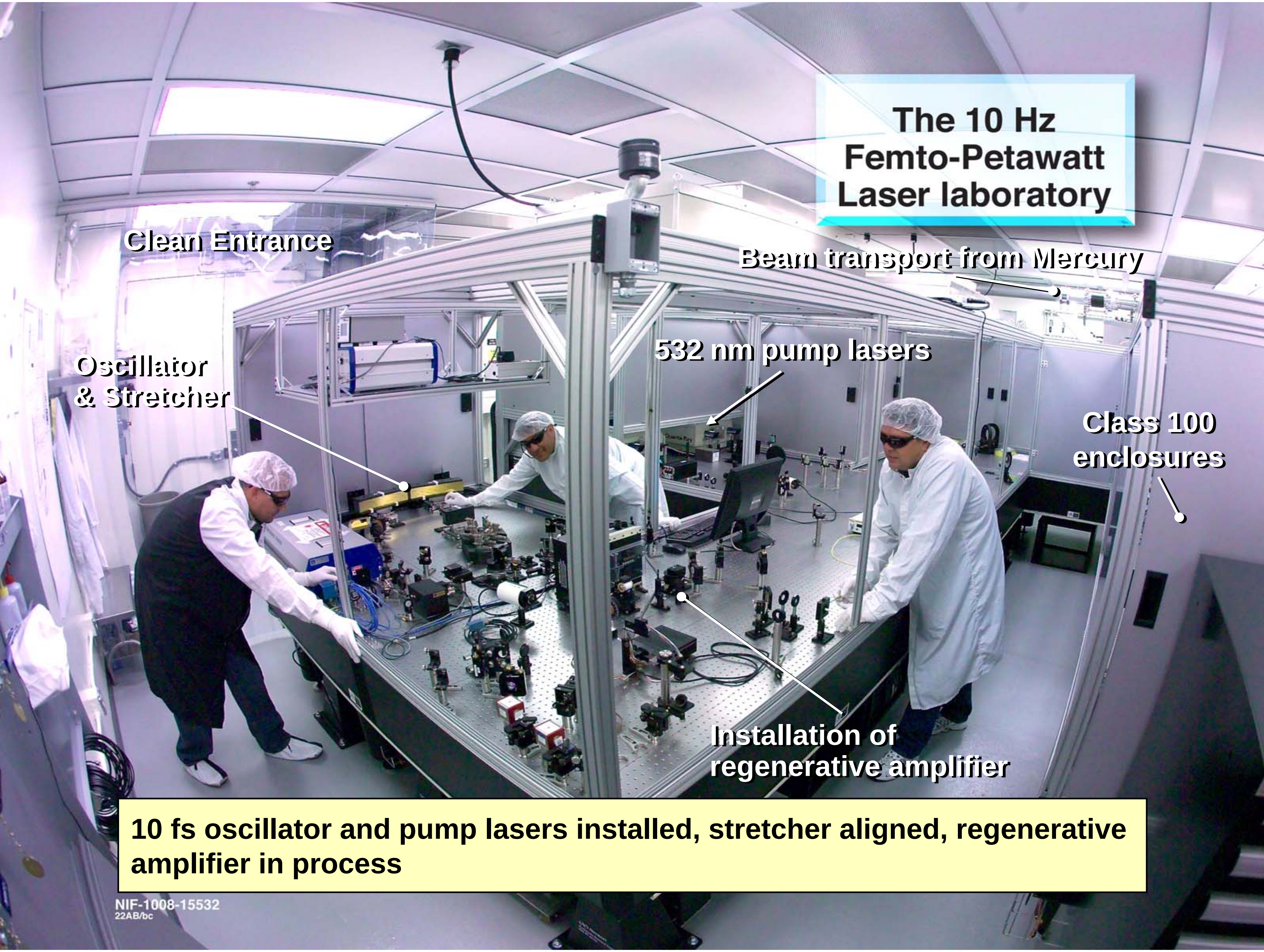
22AB/bc

The 10 Hz Femto-Petawatt Laser laboratory



10 fs oscillator and pump lasers installed, stretcher aligned, regenerative amplifier in process

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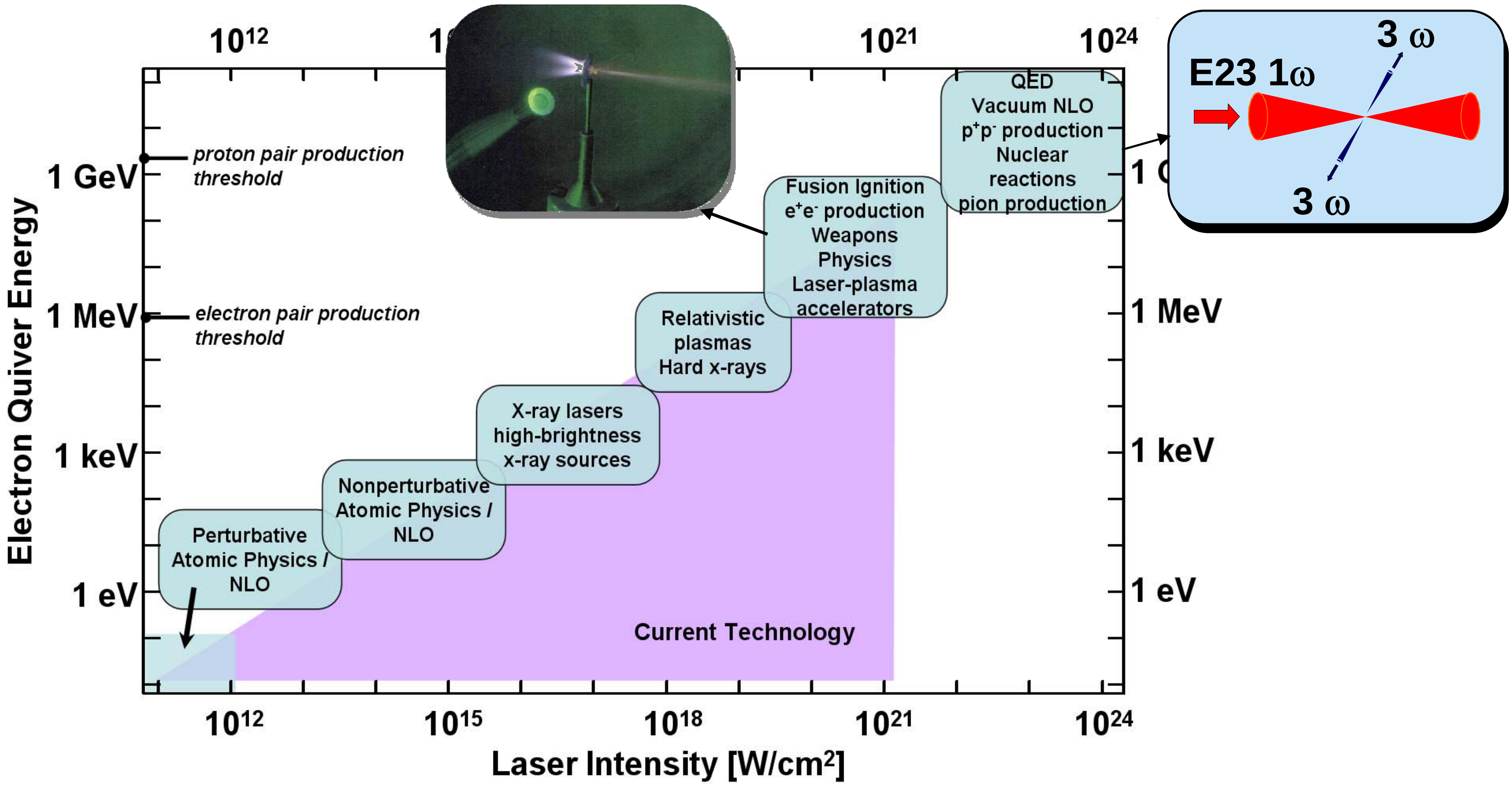
The 10 Hz Femto-Petawatt Laser will access a new high-field physics regime



The laser will provide 150 W (36000 PW shots/hr) which can generate a flux of X-rays, electrons, protons, and neutrons for high intensity applications

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Schott Glass Technologies
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Zygo