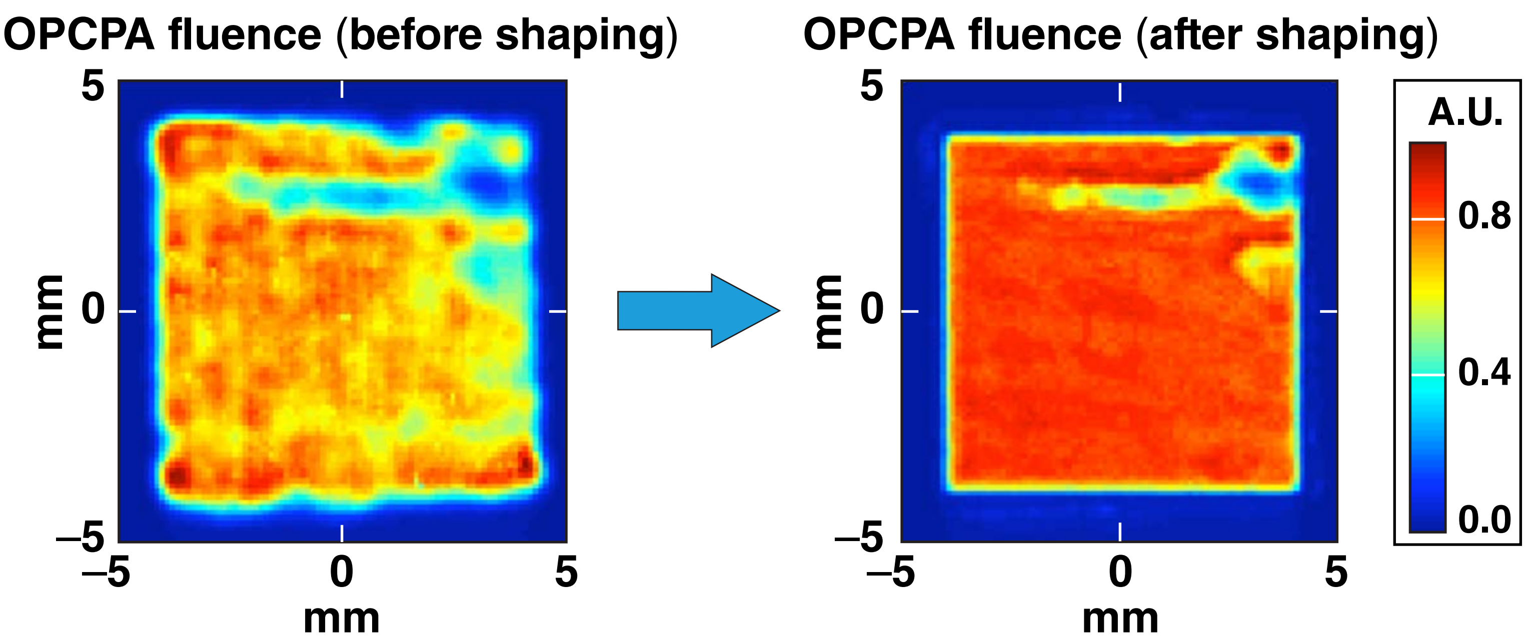
A High-Resolution, Adaptive Beam-Shaping (HRABS) System in a Multi-Terawatt Laser



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Summary

A high-resolution beam-shaping system (HRABS) was demonstrated in a multi-terawatt laser

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- Fluence spatial variations and wavefront errors limit the laser-system energy and focusable power density on target
  - HRABS improves both using a spatial-light modulator in a closed loop
- Beam shaping was demonstrated in an OPCPA-based multi-terawatt laser
  - peak-to-mean of fluence is reduced by about a factor of 2
  - HRABS is ready to be implemented in OMEGA EP long-pulse beamlines
- Damage threshold of the SLM is 230 mJ/cm^2

HRABS improves the performance of high-power laser systems.

E19206

S.-W. Bahk *et al.*, Opt. Express 18, 9151 (2010).

An electrically addressed SLM and a high-resolution Shack-Hartmann wavefront sensor are primary devices

Spatial Light Modulator (SLM)

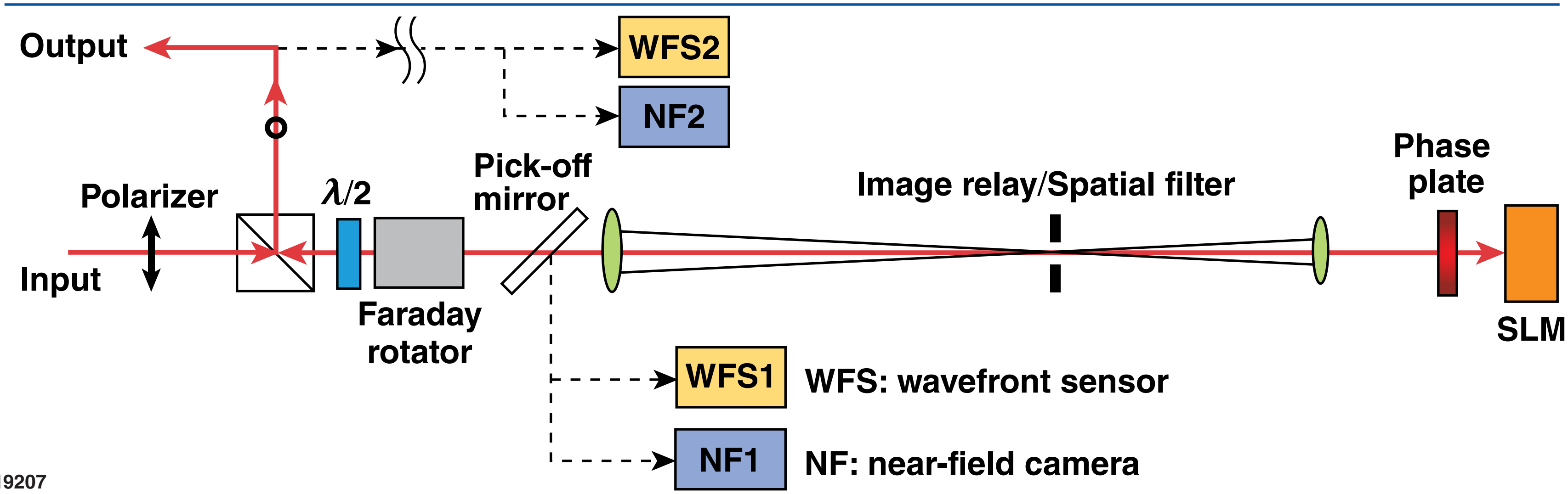
X10468 head and controller

Hamamatsu LCOS SLM (X10468)	
Area	12×16 mm^2
Control points	600×792 (20 μm)
Dynamic range at 1 μm	2 waves

Imagine Optic Shack–Hartmann sensor (HASO128)	
Area	14×14 mm^2
Resolution	133×133 (114 μm)

Wavefront Sensor (WFS)

A typical setup



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HRABS controls amplitude by introducing high frequency phase and scattering light (carrier method)

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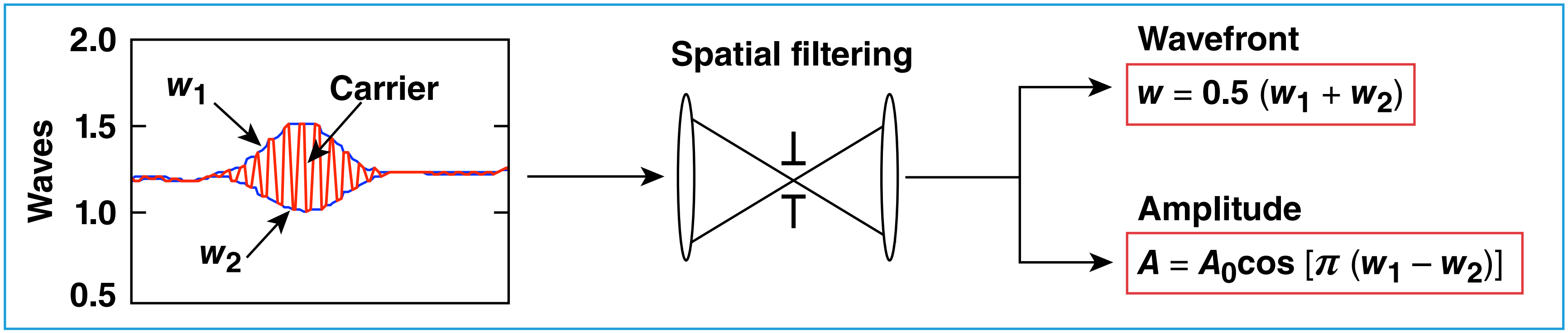
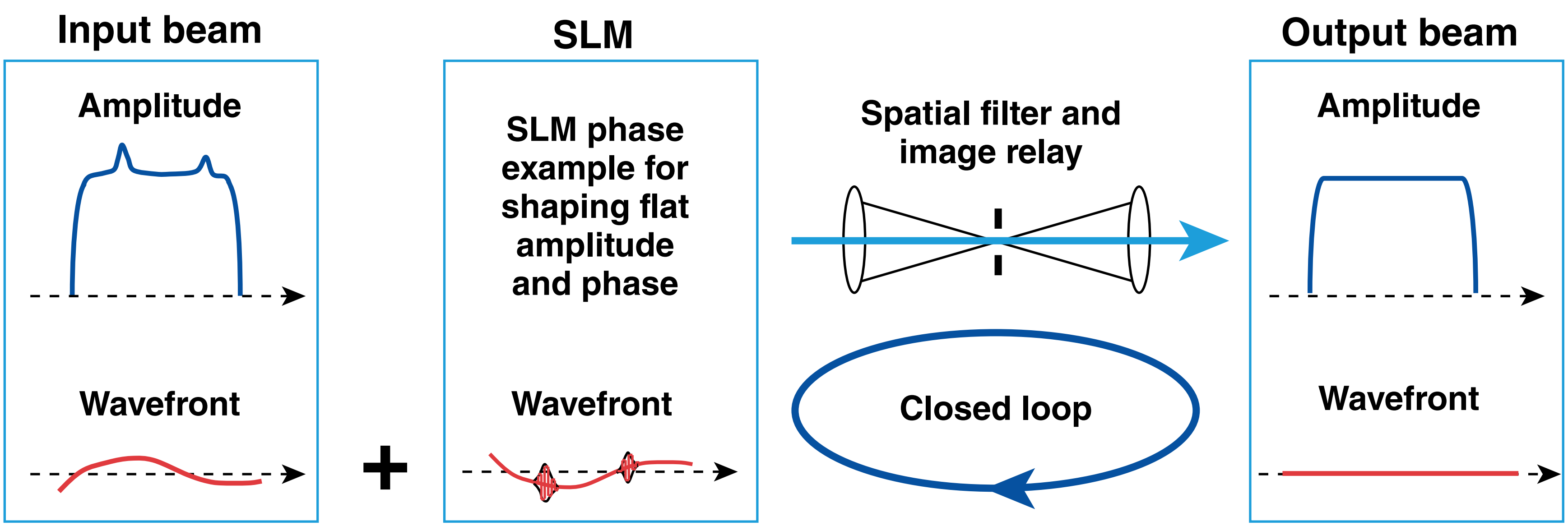
Schematic of carrier method



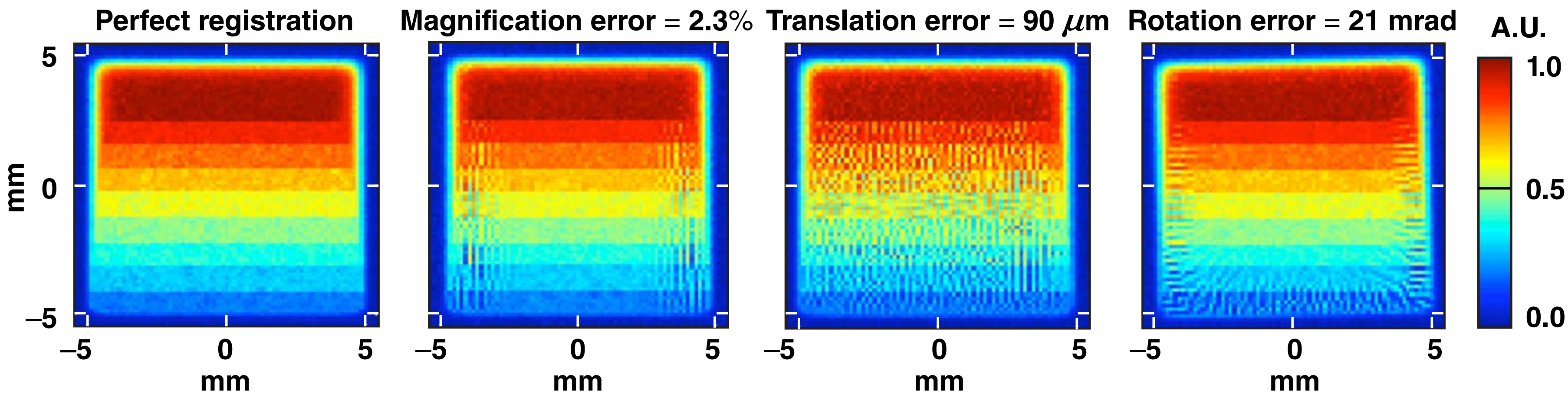


E19208

V. Bagnoud and J. D. Zuegel, Opt. Letter 29, 295 (2004).

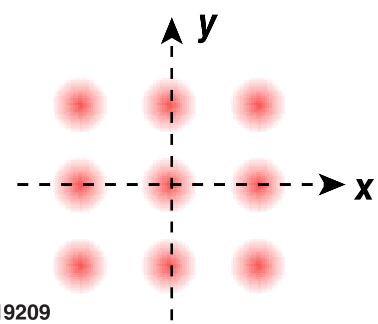
The spatial registration error should be less than half the resolution of the measurement system

Staircase beam-shaping simulation with various spatial registration errors (resolution = 142 μm)



- **Numerical optimization is used to overcome this problem**

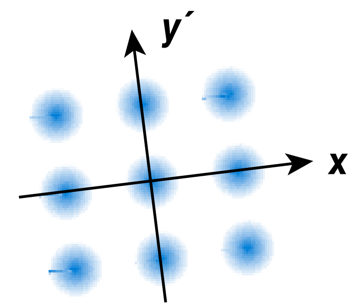
Wavefront pattern (W) on SLM



Optimize (M_x, M_y, x_0, y_0, θ) for minimum difference between W' and W

$$\begin{cases} x' = (M_x\, x - x_0) \cos\theta + (M_y\, y - y_0) \sin\theta \\ y' = -(M_x\, x - x_0) \sin\theta + (M_y\, y - y_0) \cos\theta \end{cases}$$

Measured wavefront (W') on the sensor



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The influence of energy fluctuation is stabilized by using a spatially disjoint anchoring technique

- The fluctuation in total energy of a laser beam renders the closed-loop operation unstable
  - the algorithm cannot distinguish whether the fluence change was caused by its own control or by energy fluctuation
- A two-step iteration overcomes this problem (assuming no extra energy measurement)
  - two disjoint regions are sequentially used for energy scaling

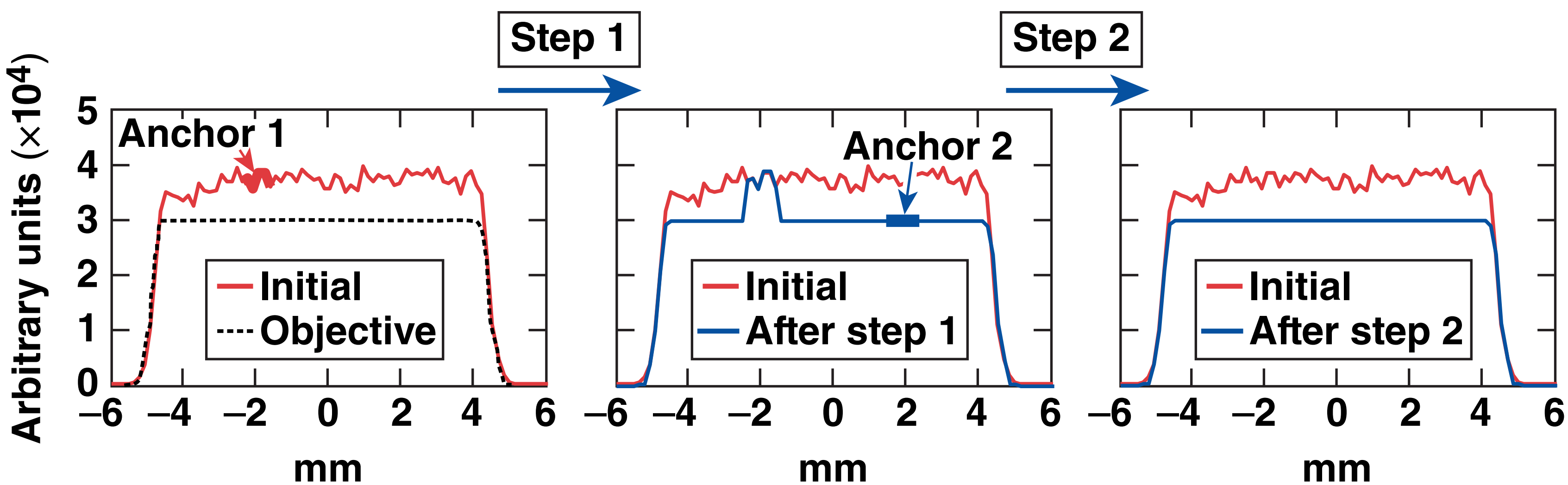
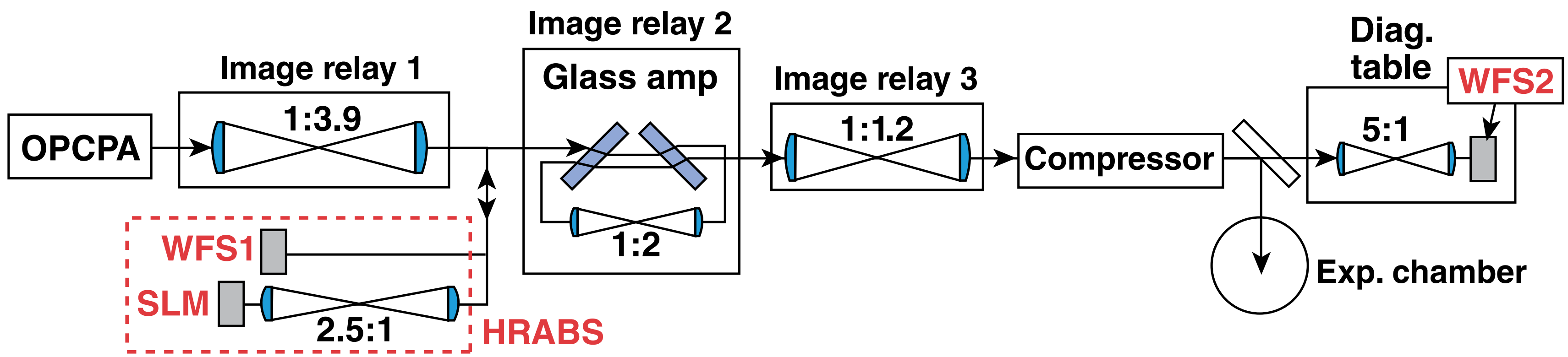


Illustration of the two-step iteration process used in flat-amplitude shaping

E19211

HRABS was installed in a multiterawatt system*



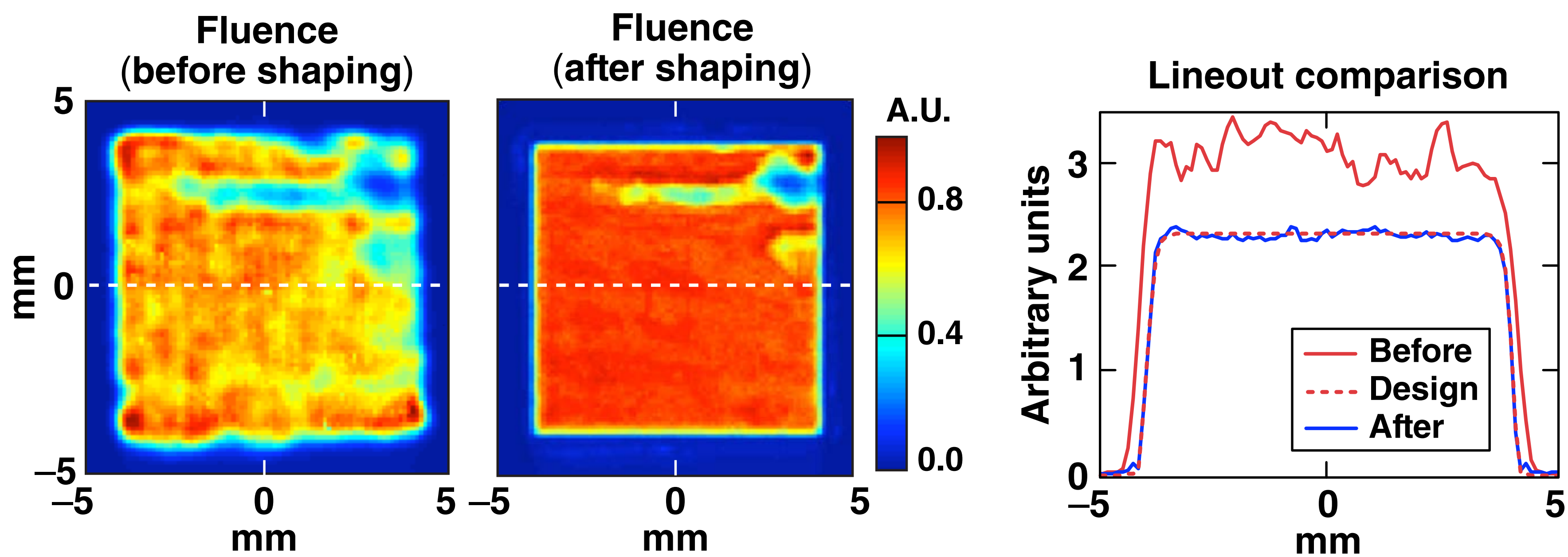
- SLM is installed after OPCPA
  - OPCPA is attenuated to 10% of the full energy
- Two wavefront sensors were installed
  - WFS1: near SLM, WFS2: on the compressor diagnostic table
  - wavefront sensors provide near-field images as well as wavefront

E19210

*V. Bagnoud *et al.*, Appl. Opt. 44, 282 (2005).

Closed-loop with WFS1

Peak-to-mode of the OPCPA beam improves from 45% to 20%



- p–m = 45%
- relative rms = 21%

- p–m = 20%
- relative rms = 5%

$$\text{Peak-to-mode} \equiv \text{max of} \left(\frac{F_{\text{actual}} - F_{\text{mode}}}{F_{\text{mode}}}\right)$$

$$\text{Relative rms} \equiv \text{rms of} \left(\frac{F_{\text{actual}} - F_{\text{ideal}}}{F_{\text{ideal}}}\right)$$

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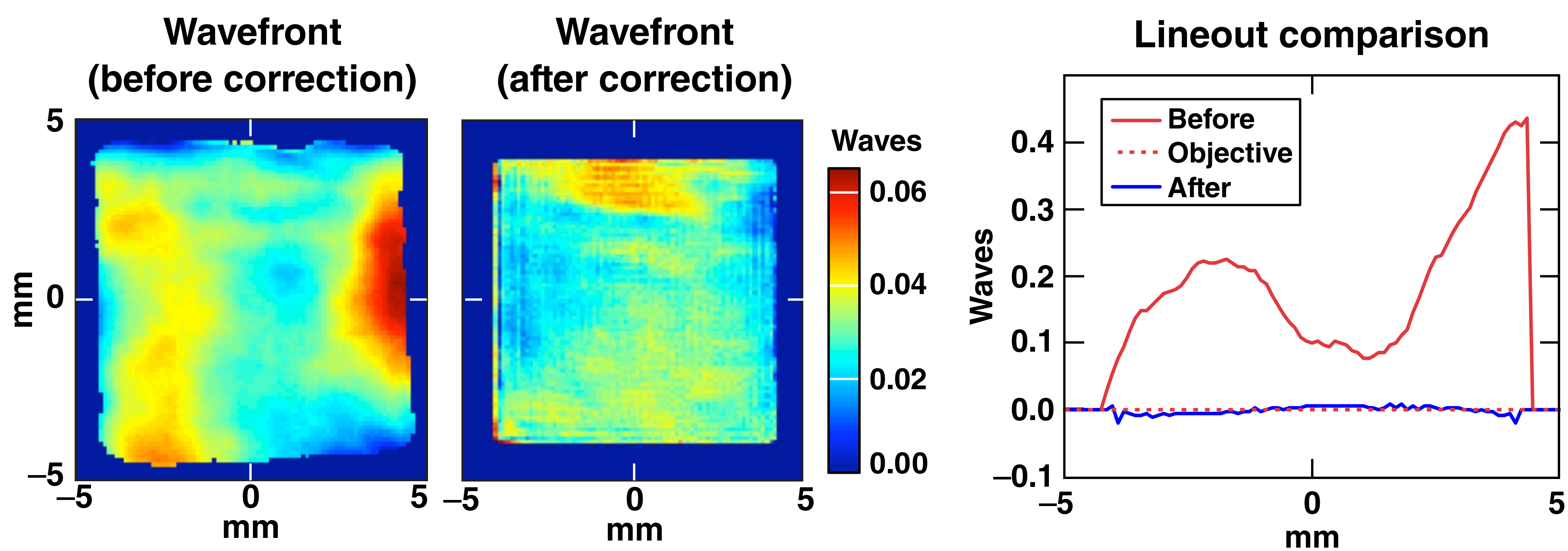
Closed-loop with WFS1

OPCPA wavefront is corrected within 0.01 waves rms



- p–v = 0.6 waves
- rms = 0.09 waves

- p–v = 0.066 waves
- rms = 0.007 waves

E19213

Beam shaping converges within 20 iterations

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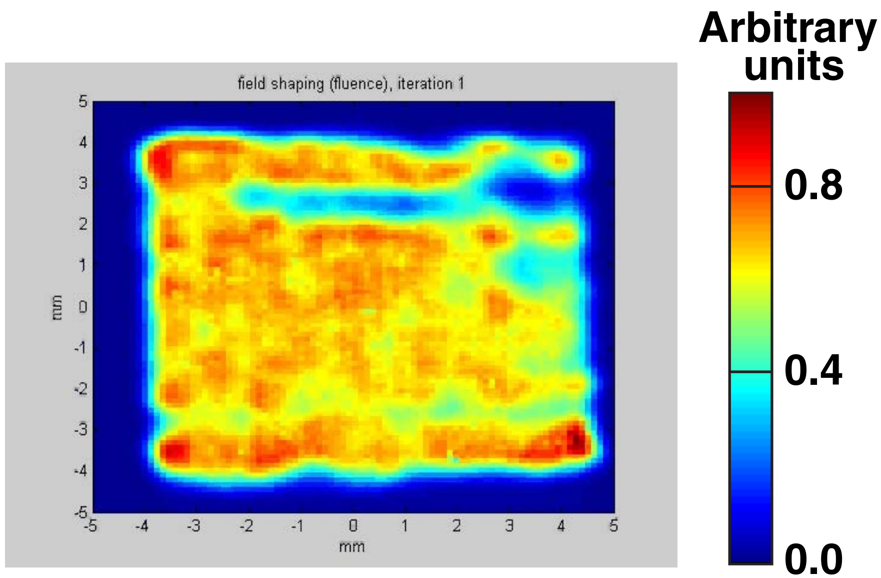
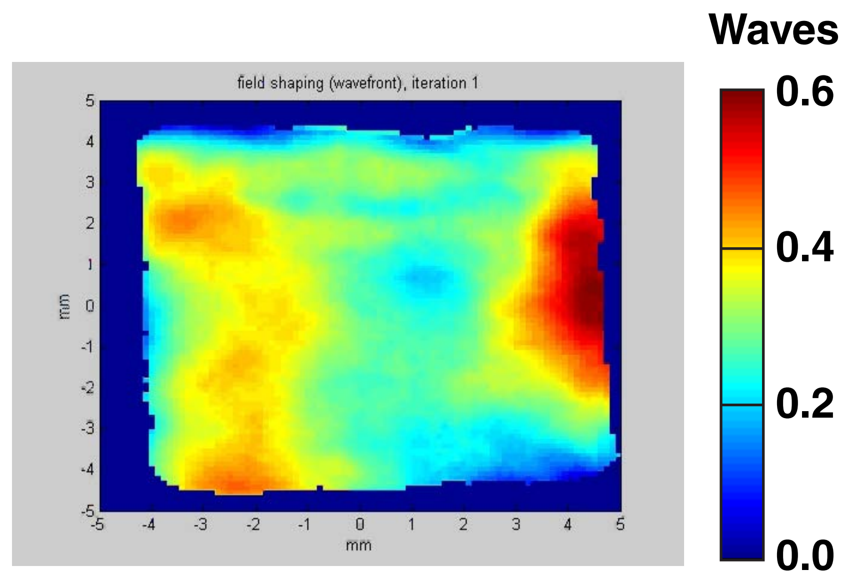
Fluence movie



Wavefront movie



* Fluence and wavefront map at each iteration belongs to the same OPCPA pulse

Wedge aberrations in the system introduce image blurring at WFS2

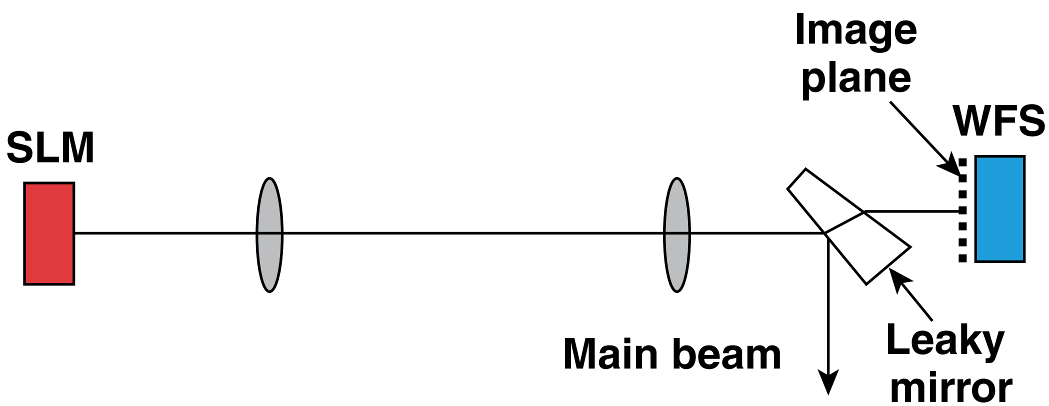
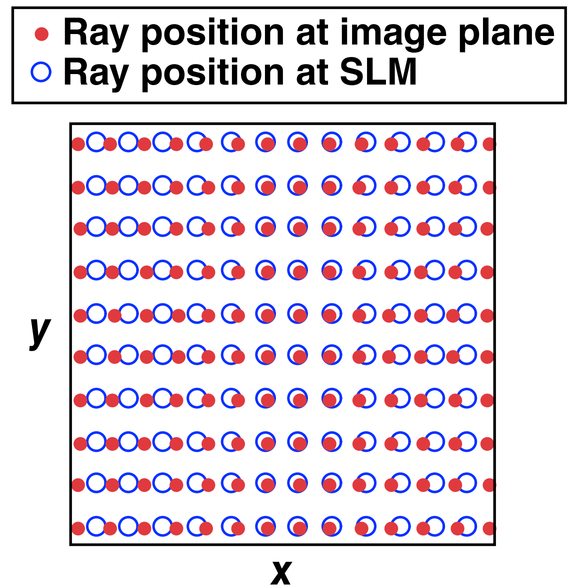


Illustration of mapping error

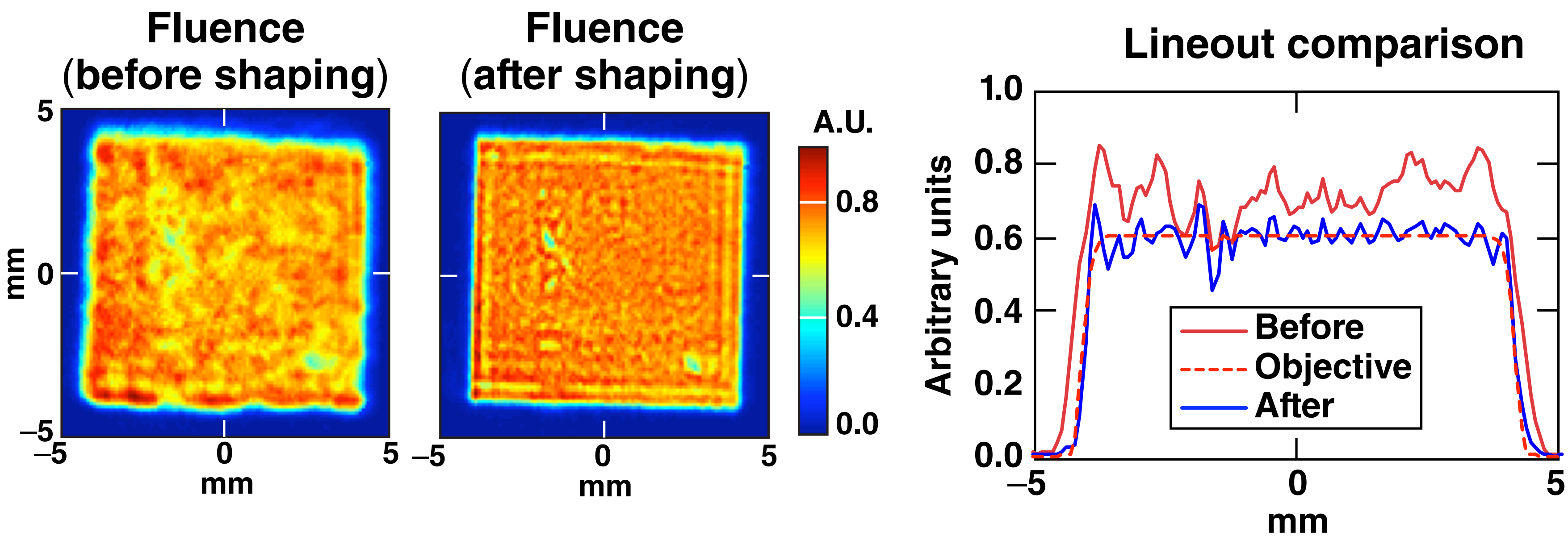


- A wedge in the imaging system breaks the Abbe sine condition
  - the more the tilt and the wedge angle, the more blurred
- A 3° wedge was found and removed for WFS2 imaging
  - there are still unexplained wedges distributed in the system

SLM map is numerically smoothed at each iteration.

E19218

Peak-to-mode of the OPCPA beam improves from 40% to 25%



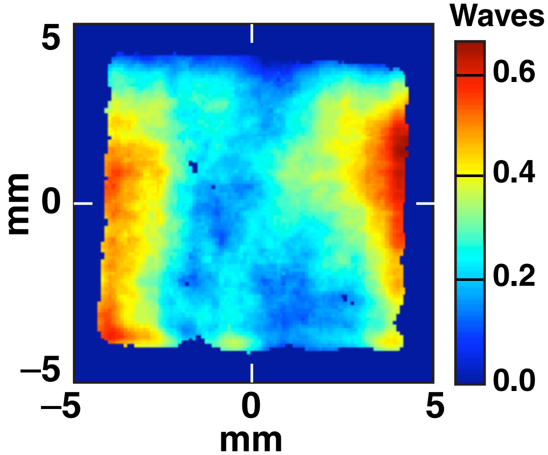
- p–m = 40%
- relative rms = 9%

- p–m = 25%
- relative rms = 7%

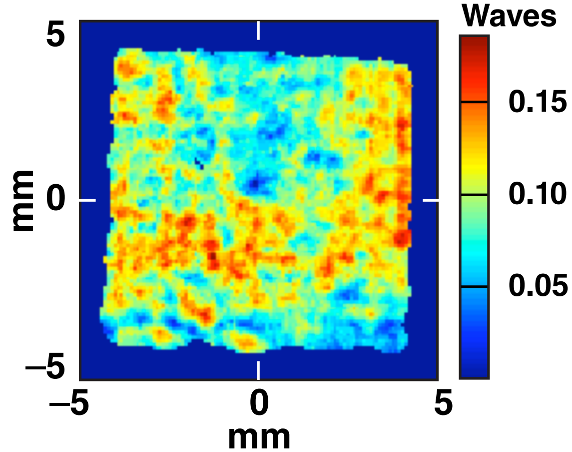
SLM map is smoothed by convolving with a blurring function.

OPCPA wavefront is corrected within 0.04 waves rms

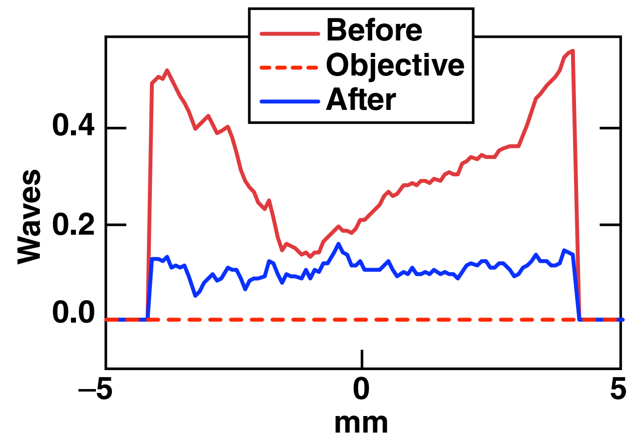
Wavefront (before correction)



Wavefront (after correction)



Lineout comparison



- p–v = 0.67 waves
- rms = 0.16 waves

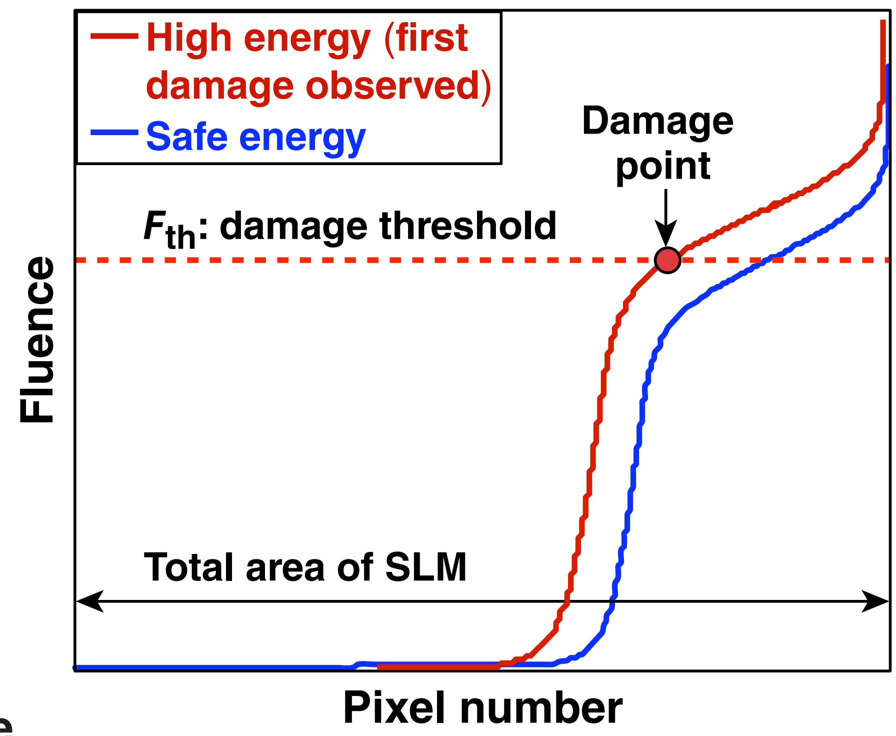
- p–v = 0.19 waves
- rms = 0.04 waves

SLM map is smoothed by using Legendre basis functions.

Laser-damage threshold of the SLM at 5 Hz is 230±10 mJ/cm^2

- Small-spot damage threshold ranges from 0.6 to 2 J/cm^2 indicating defect-limited performance
  - large area damage test is needed
- The damage threshold is determined by slowly ramping up the energy over a large sample area
  - distribution of defects is sparse (about 4 pixels over the whole area)
  - damage does not necessarily occur at the peak fluence
  - three samples (one active, two passive) exhibit the same damage threshold

Sorted fluence curve



The SLM sample survived 9 h of irradiation (5 Hz) at an apparent energy density of 230 mJ/cm^2.
- cf. apparent damage fluence is 280 mJ/cm^2.

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