Beam shaping with Spatial Light Modulator (for DiPOLE/HiLASE front-end)

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projekt podporovaný:

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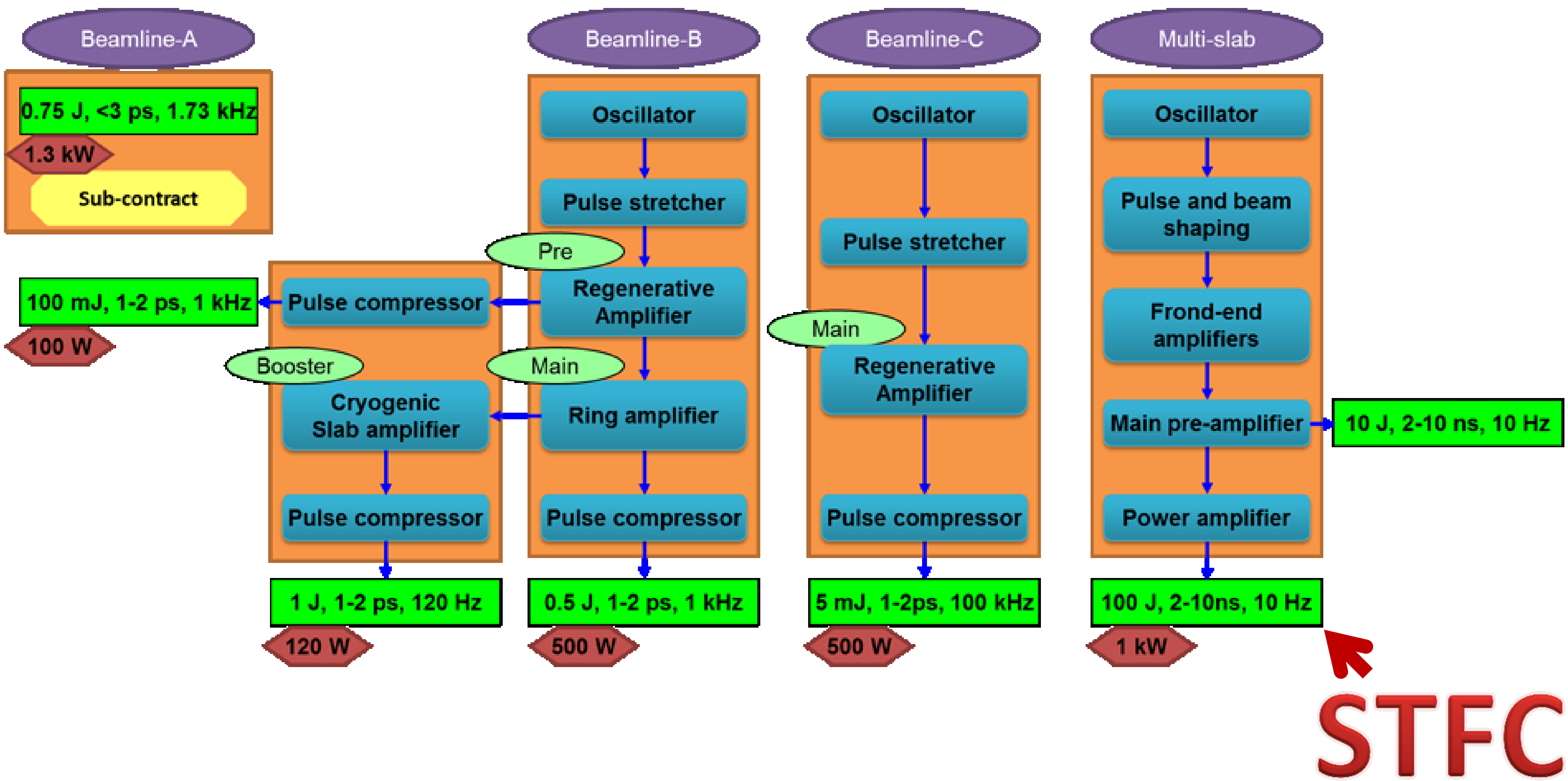
HEC-DPSSL 2014, Oxford

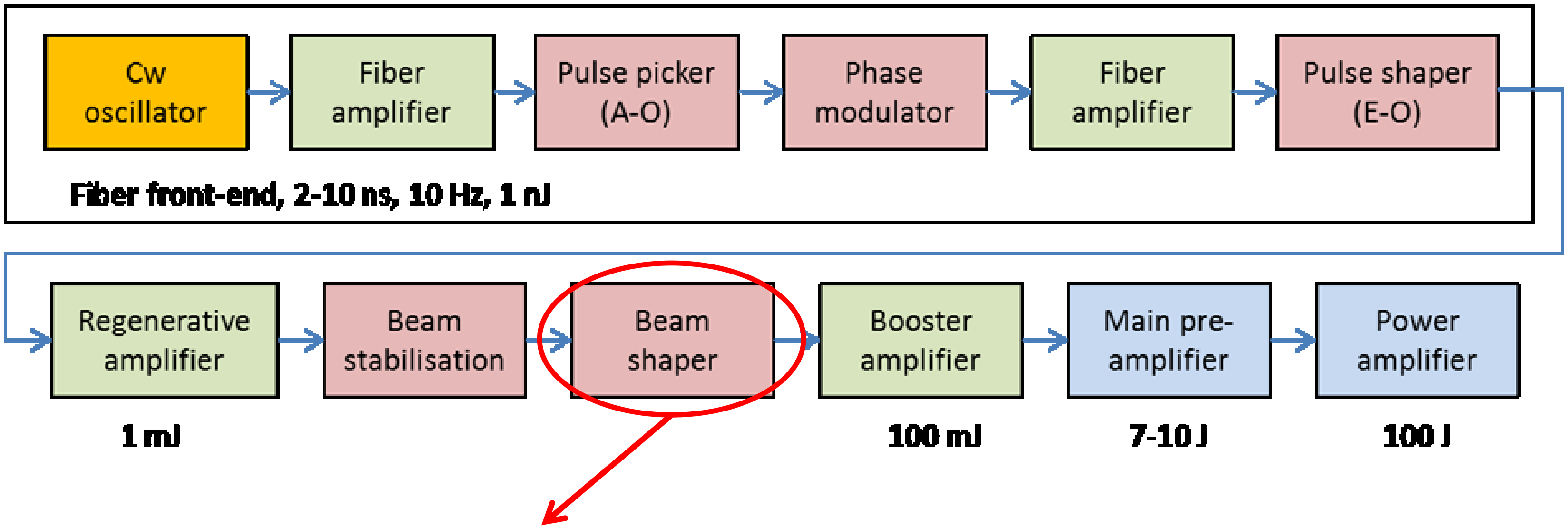
Outline

- HiLASE project
- Motivation
- Liquid crystals for light shaping
- Spatial shaping with phase modulator
  - in far field (CGH)
  - in near field
- Amplitude shaping with phase spatial light modulator
- Preliminary experimental results
- Wavefront deformation
- Summary

HiLASE project



100 J 10 Hz laser system



Creates square beam from Gaussian
Limits the beam inhomogeneity

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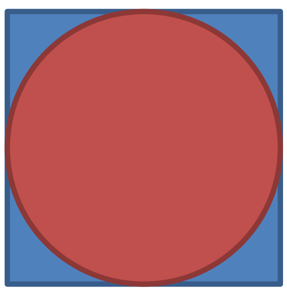
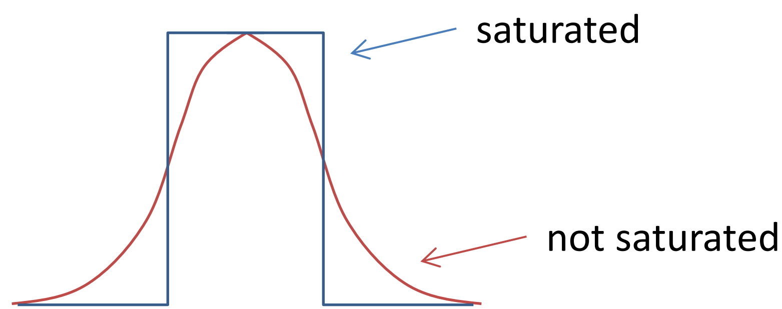
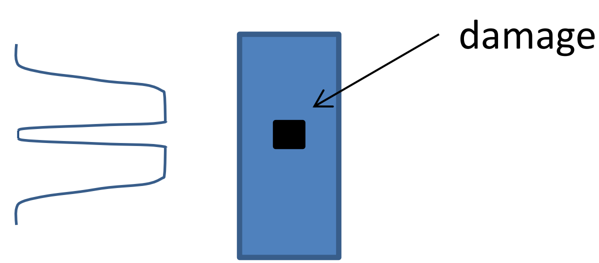
Motivation

- Efficient space utilization by amplifiers in stack (square)
- Efficient energy extraction from amplifier (flat top beam)
- Compensation of non-uniform gain.
- Preventing damage growth by masking part of the beam







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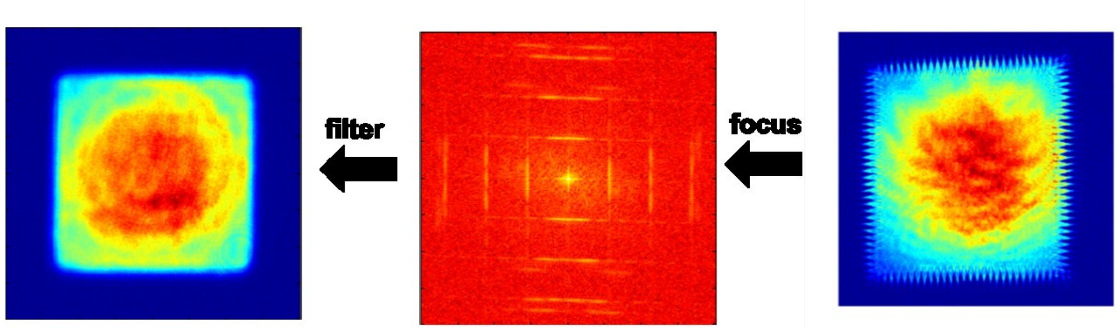
Beam shaping

Current status - Serrated aperture



Seed beam to the main amplifier

FFT of the image

Beam through serrated aperture

Proposed - Liquid crystals spatial light modulator

Beam shape

Required shape

Transfer function

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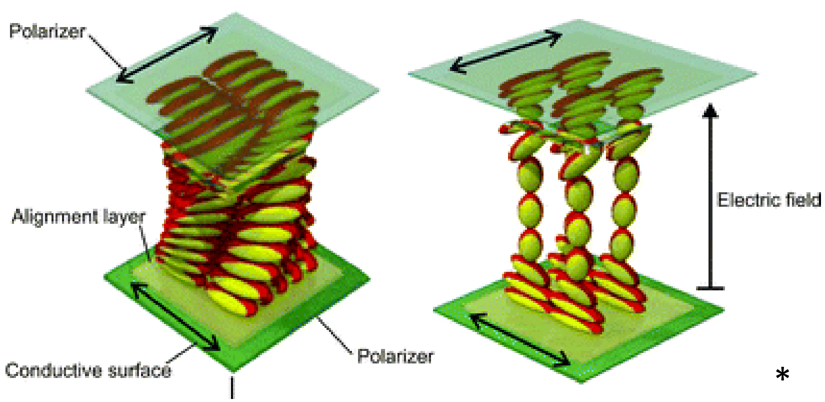
Liquid crystals for light shaping

Birefringent crystals – axis can be rotated in electric field

Twisted nematic

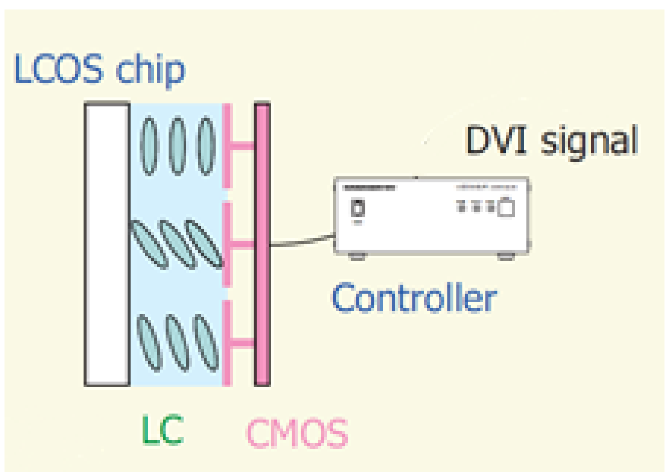
- molecule rotates around the propagation direction
- changes polarization and phase

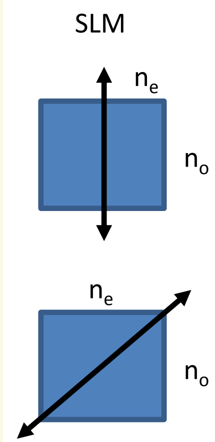


*

Parallel aligned nematic

- molecule rotates in direction of propagation
- changes phase or phase and polarization





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*Hoogboom - Journal of Material Chemistry, v16, 2006

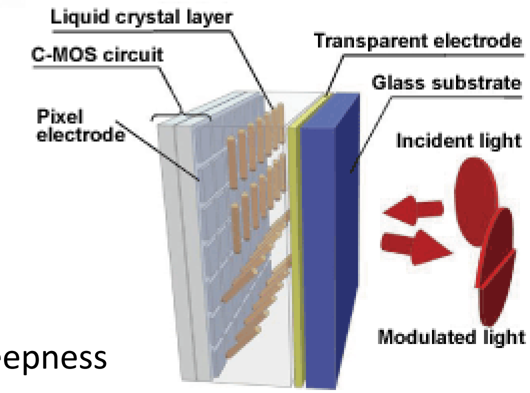
**Hamamatsu

Hamamatsu SLM

Parallel aligned nematic liquid crystal Spatial light modulator

- 2π phase shift
- Wavelength 1000-1100 nm
- Reflectivity > 99%
- Fill factor > 98%
- Resolution 800 x 600
- Pixel size 20 μm

*



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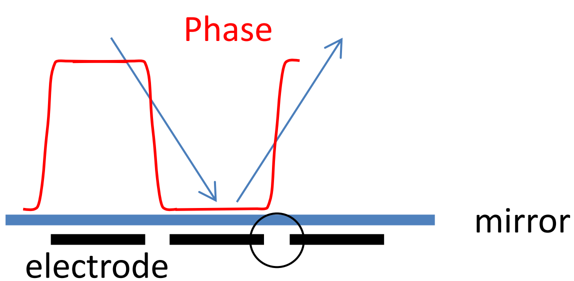
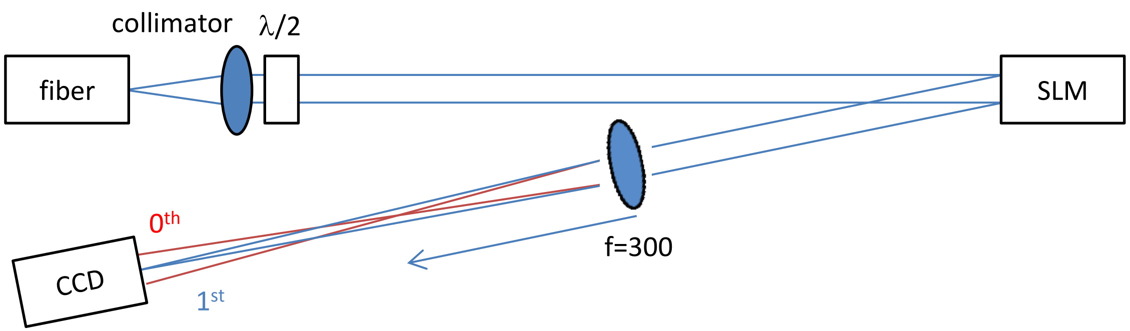


gap given by fill factor – affects phase edge steepness

*Hamamatsu

Far-field = computer generated holograms

Creates Fourier transform of an image in desired shape with not light loss

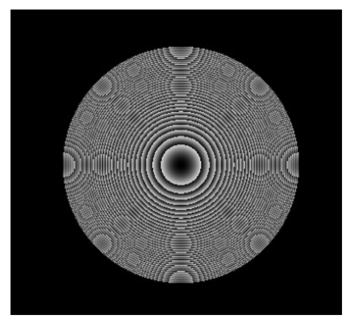


CHG + Fresnel lens

Required far field image

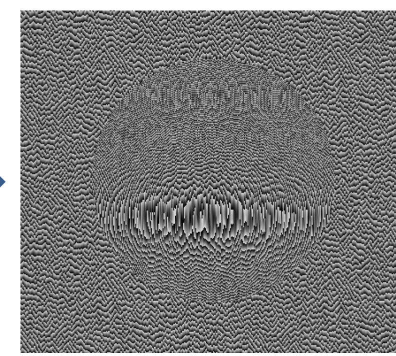
FFT^{-1} +

Fresnel lens



Removes residual 0^{th} order

Computer generated hologram



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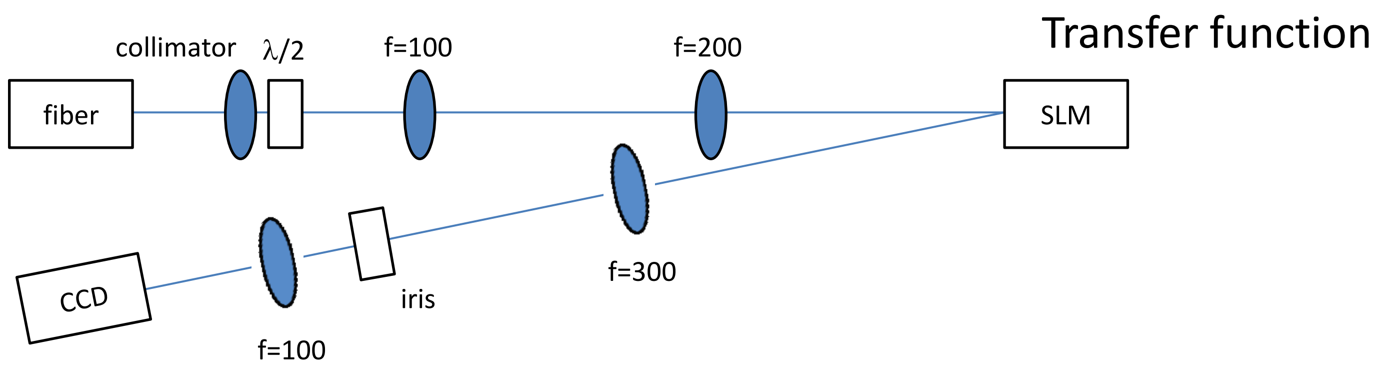
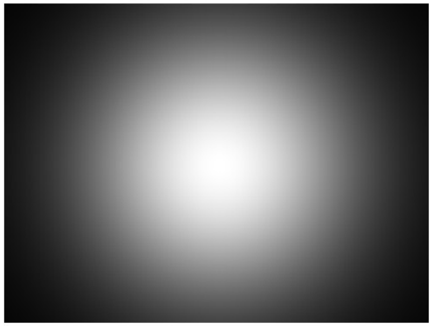
*Hamamatsu LCOS control SW

Near-field = amplitude shaping

Creates transfer function to shape the image – induces light loss

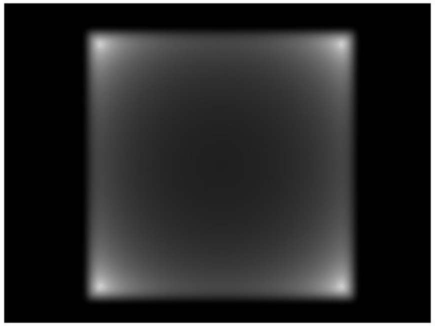


Beam shape



Required shape

Transfer function



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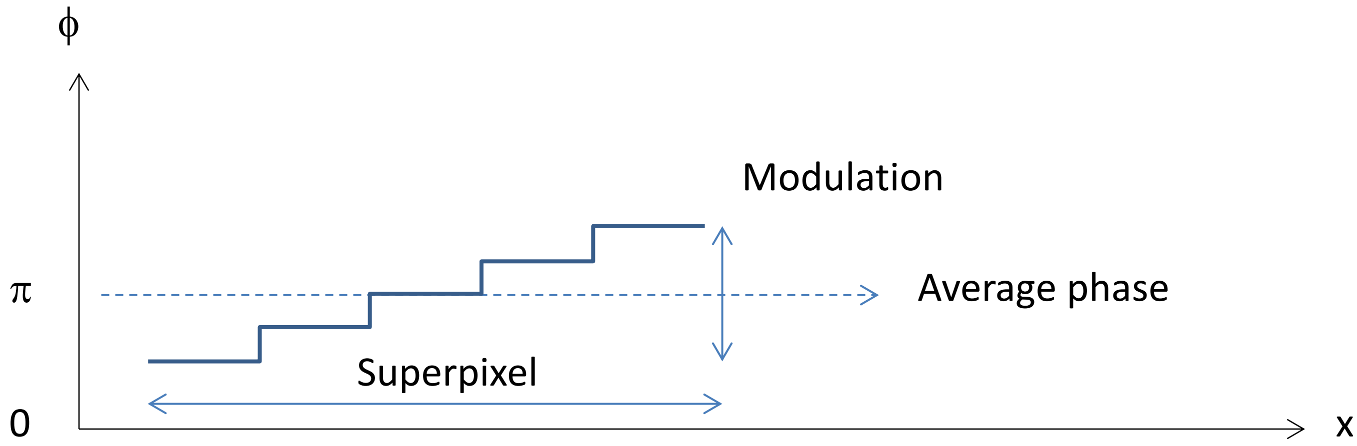
Transfer function = phase grating

Creates periodical phase modulation across SLM to form a diffraction grating that changes the beam profile based on local diffraction efficiency.

The diffraction efficiency depends on the modulation of the phase grating.

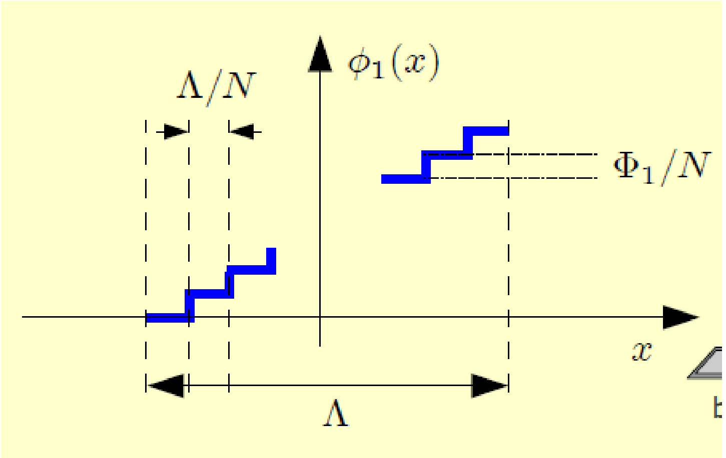
The average phase must be preserved (unless it is intentional not to).

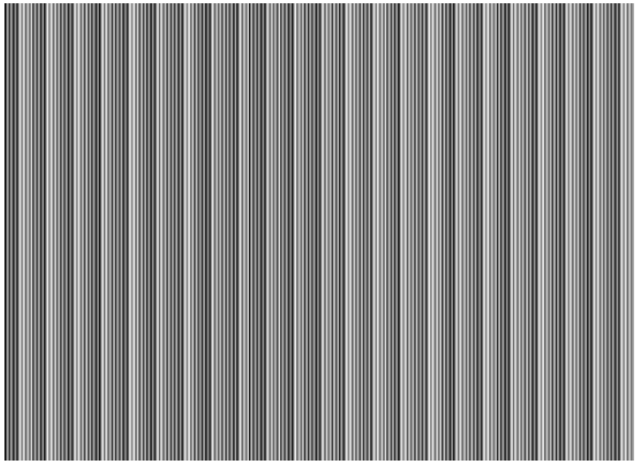


Blazed grating

Blazed phase grating with sawtooth profile

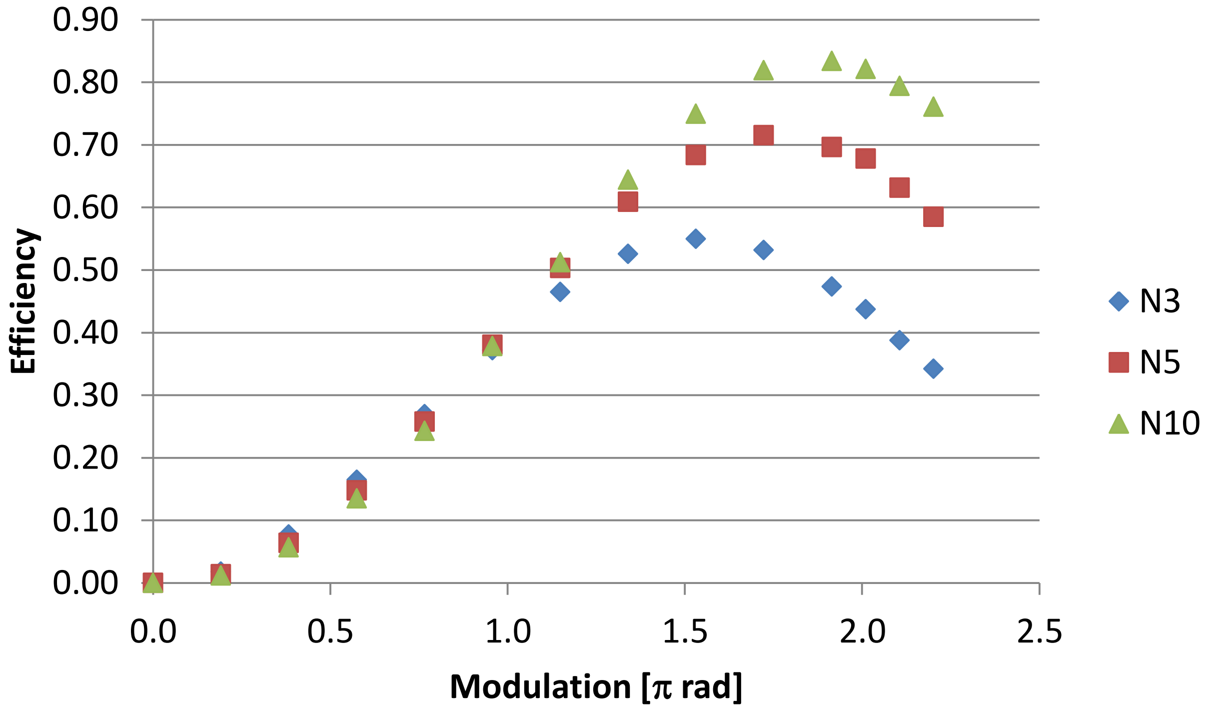
- Uses diffracted light
- Up to 100 % efficiency in 1st order (theoretical)
- 2π phase shift required
- Diffraction efficiency depends on number of steps and modulation





Blazed grating

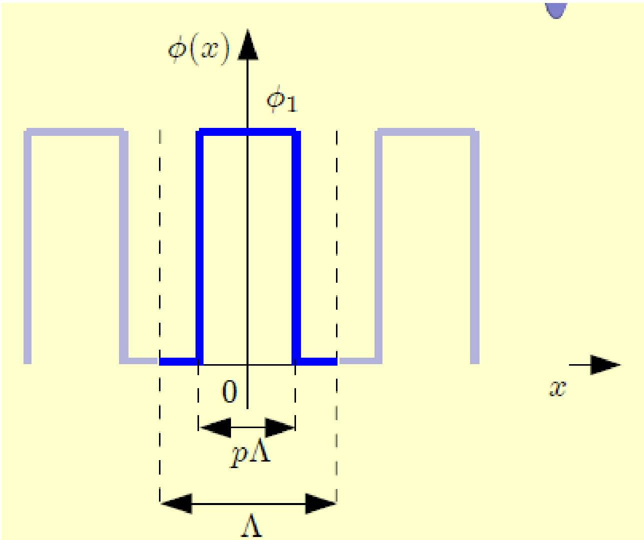
Diffraction efficiency for blazed grating for different number of steps N

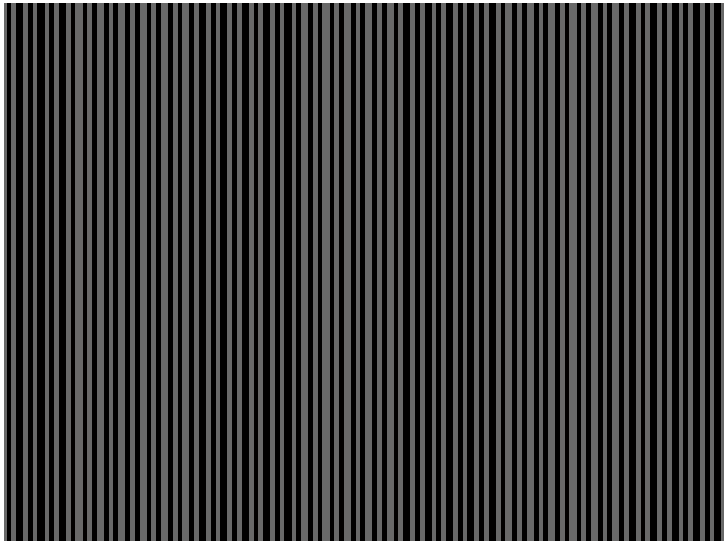


Binary grating

Binary phase grating

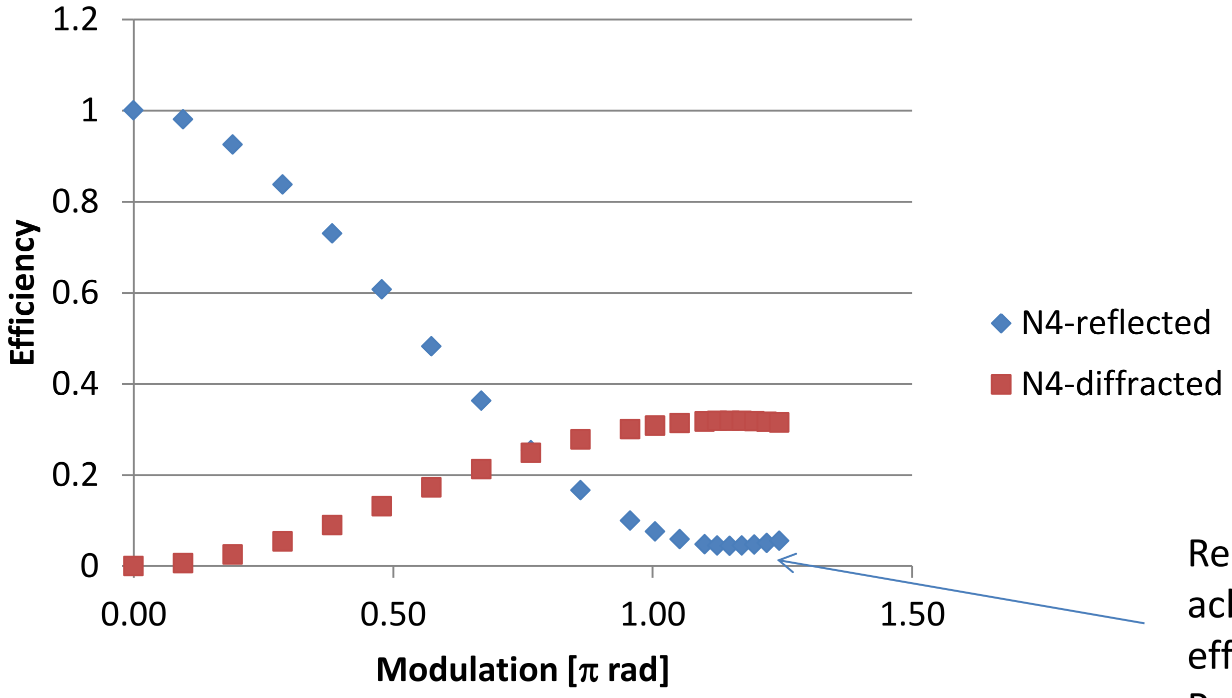
- Uses reflected or diffracted light
- Up to 100 % efficiency in 0^{th} order and 40% in 1^{st} order (theoretical)
- 1π phase shift required
- Diffraction efficiency depends on modulation





Binary grating

Efficiency for binary grating in reflection and diffraction

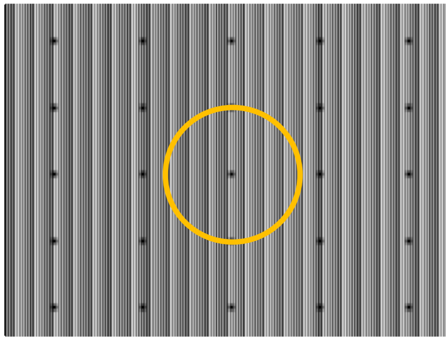


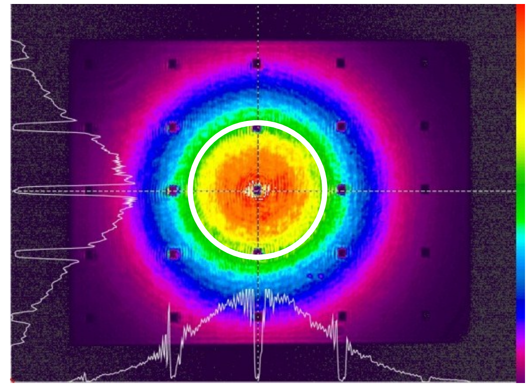
Real grating can never achieve 100% diffraction efficiency =>
Poor contrast

Beam shaping loop

Calibration – coordinates and distances are unique

SLM
800x600
position

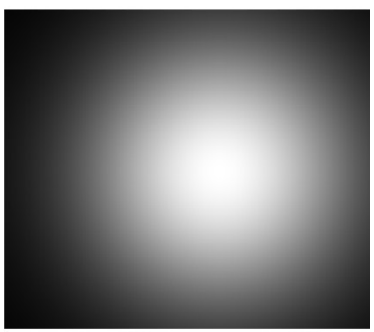




CCD
1024x1024
position

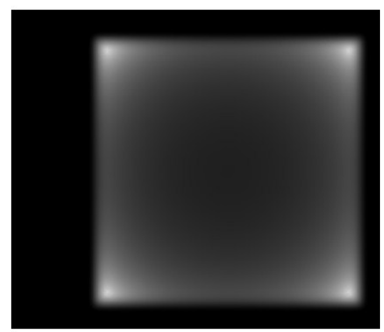
Transfer function imprint

Beam shape

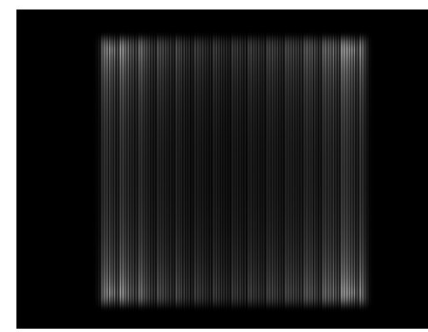


Required shape

Transfer function

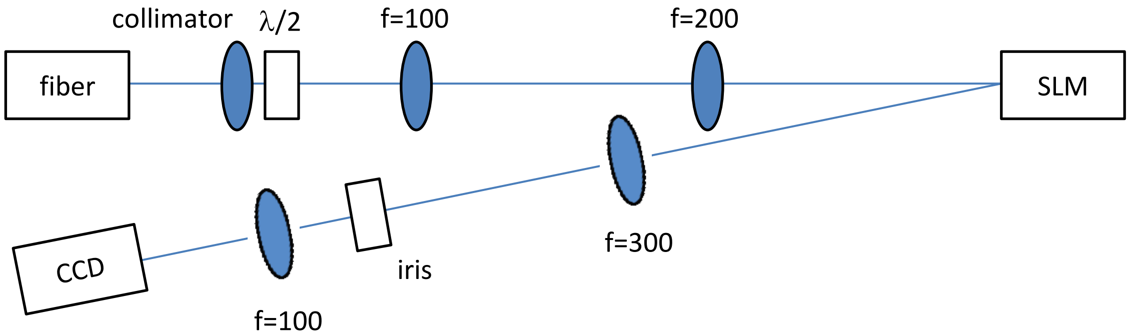


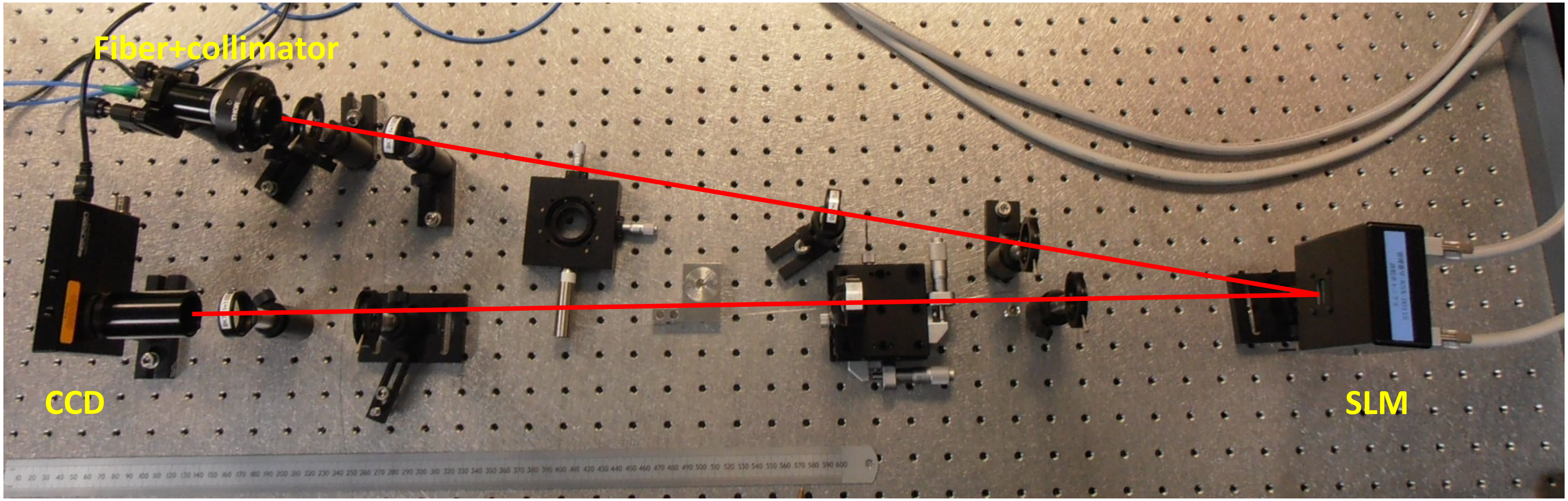
Diffraction grating



Experimental setup

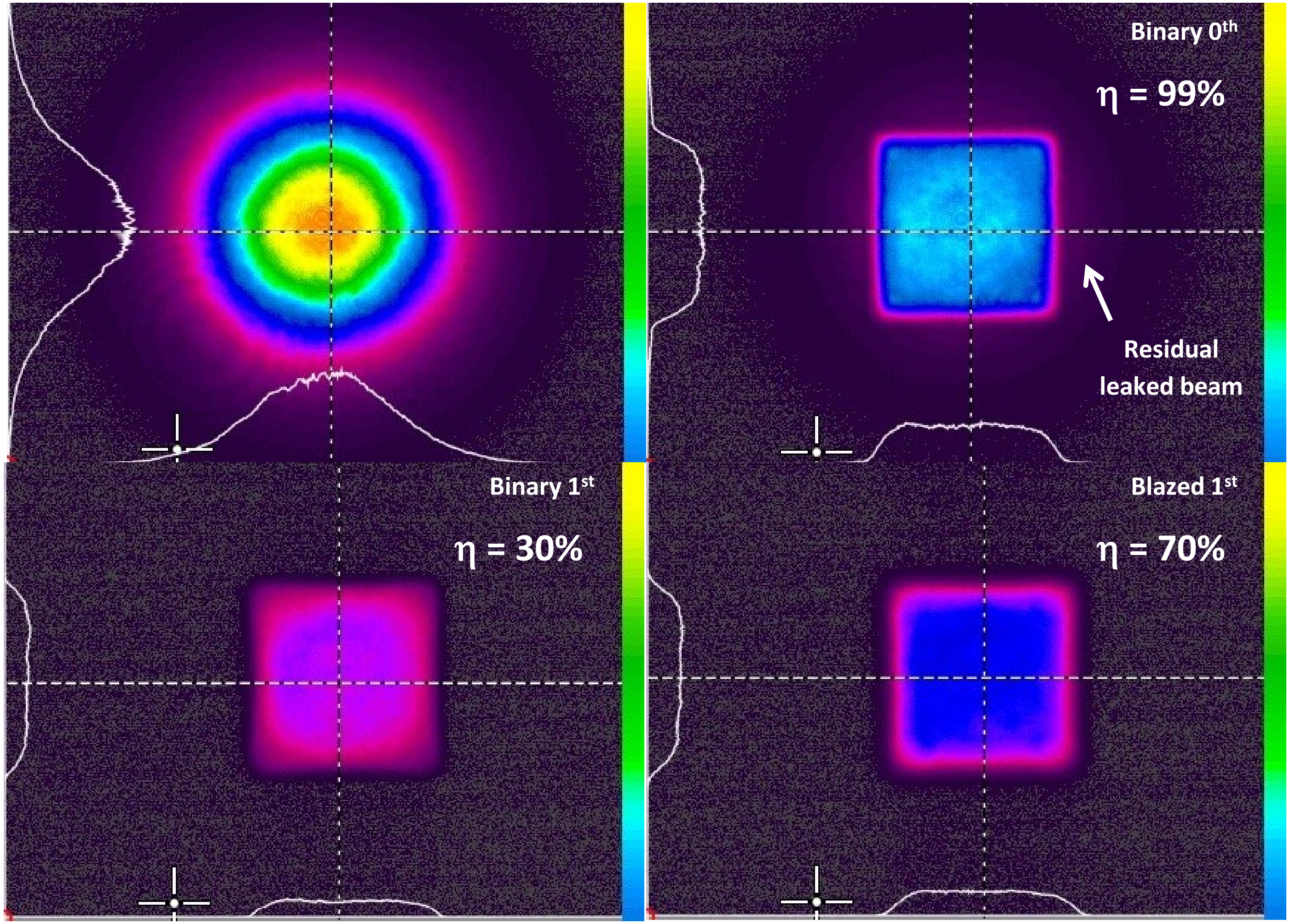
Modulator setup:
(phase grating)





Shaping results

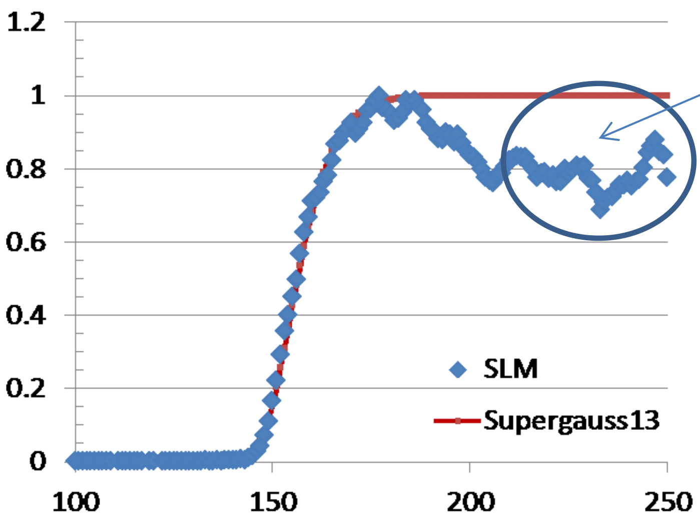
Transmission = grating efficiency (η) * shaping transmission



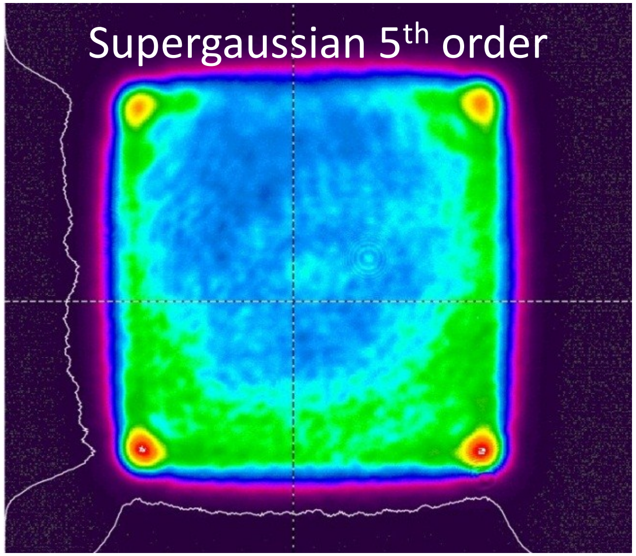
Edge steepness and beam propagation

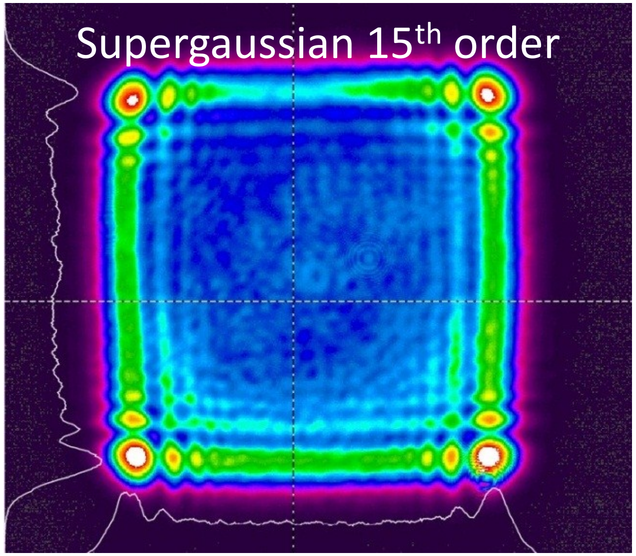
Beam edge steepness limited by diffraction

Edge steepness for Supergaussian 15th order set on SLM creates 13th order in image plane.



Solved by closed loop





Diffraction effect modulates beam in just 1*f* distance from image plane (beam size 10x10 mm, *f* = 100 mm).

Spatial filtering may help.

Beam masking

How to determine maximum steepness? Use different smoothing functions.

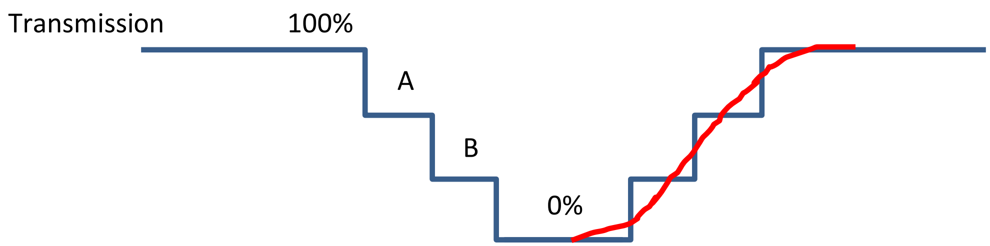
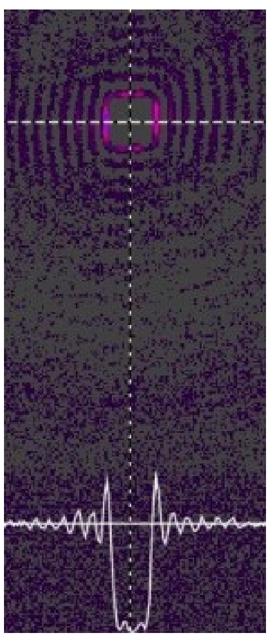
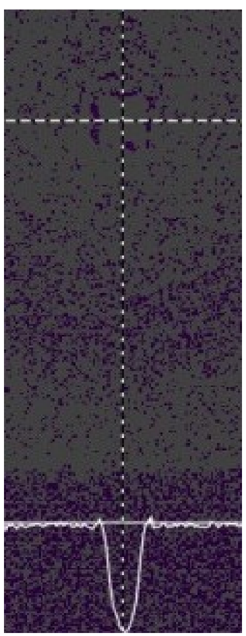


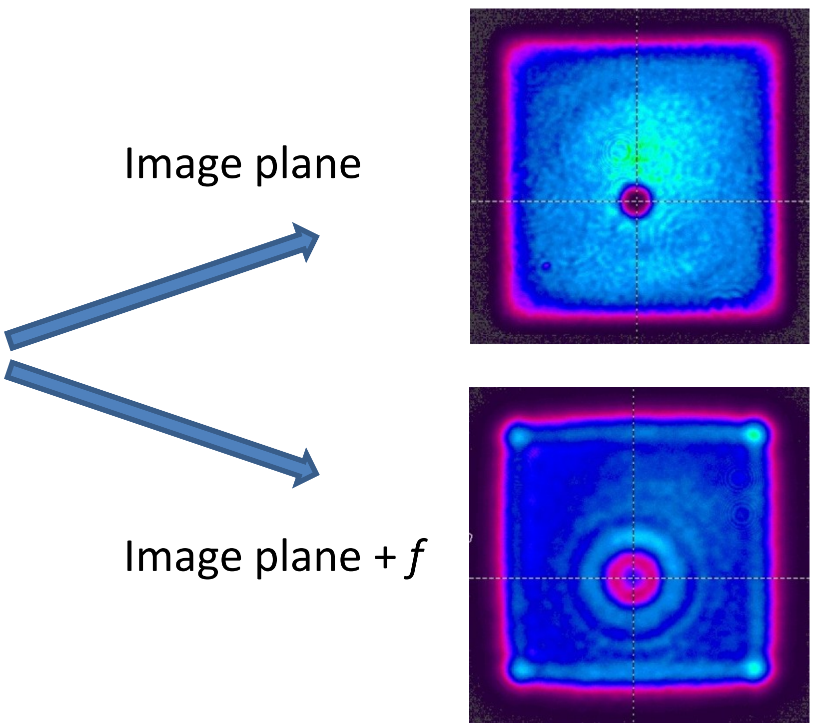
Image plane:

Step function
(A = 100%, B=0%)



"Gauss" function
(A = 75%, B=25%)



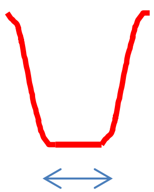


Beam masking – resolution and size

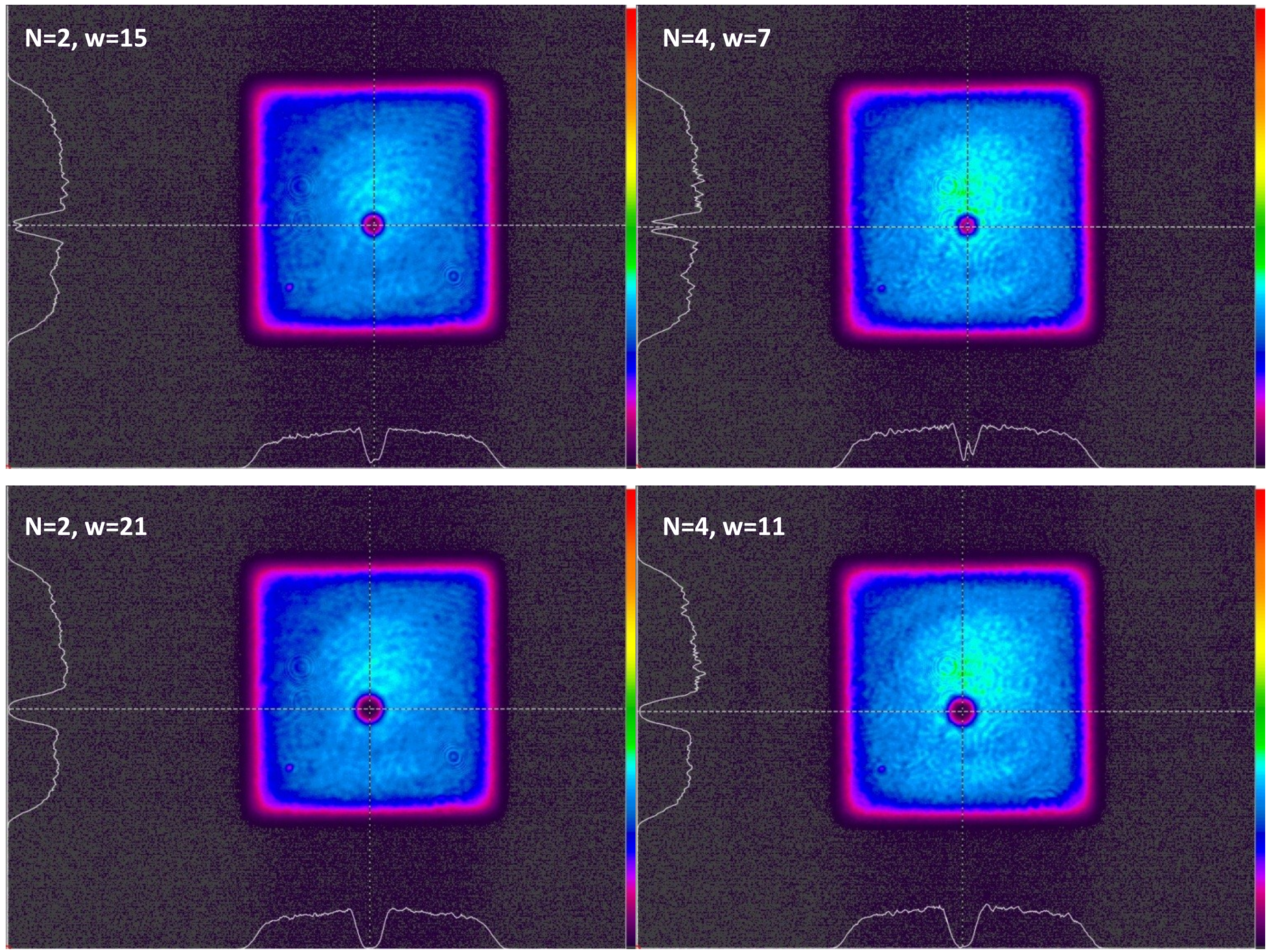
Diffraction effects can be limited by size of the mask, resolution helps only slightly.
Gauss function applied.

20 px/mm | 10 px/mm

Size 0.25 mm
(valley)

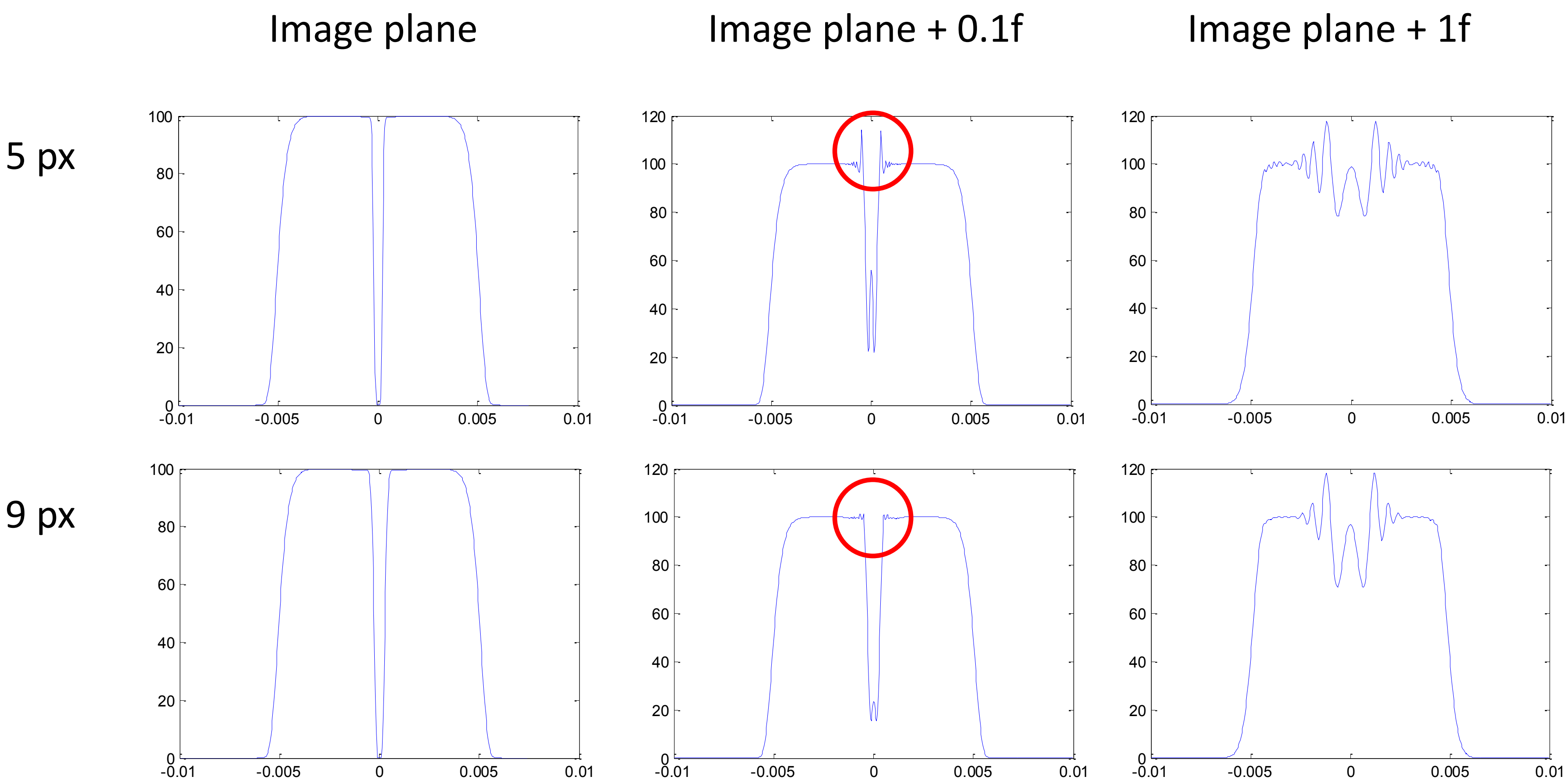


Size 0.5 mm
(valley)



Beam masking – outside image plane

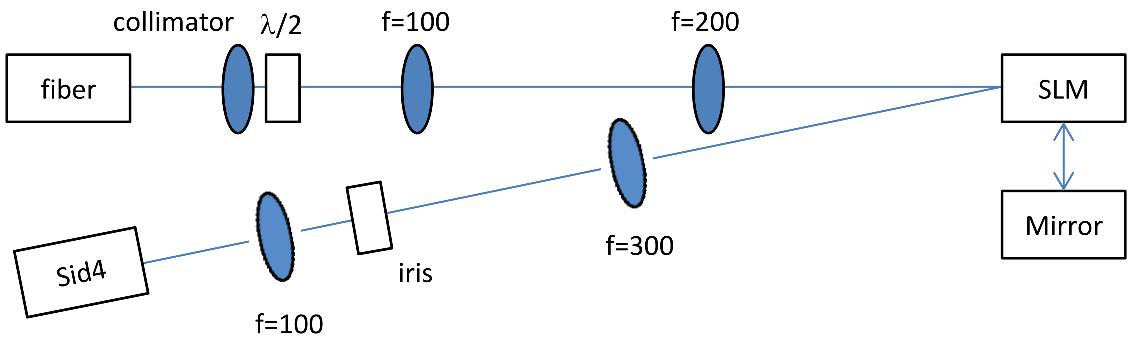
Smoothed mask calculated in MIRO – not sufficient outside image plane (5 and 9 pixels per edge, valley 0.25 mm)

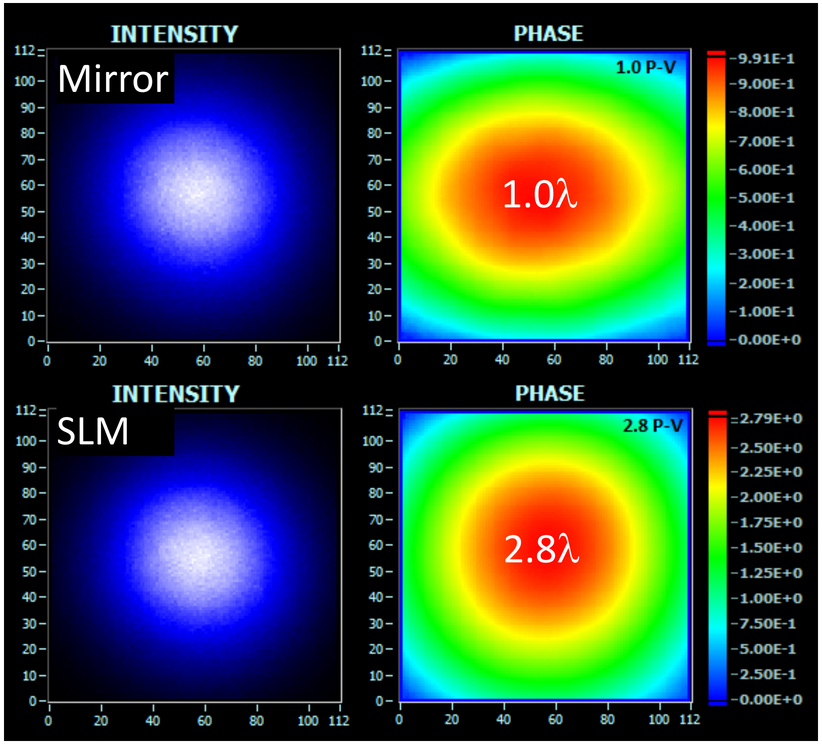


Can be spatially filtered

Wavefront distortion

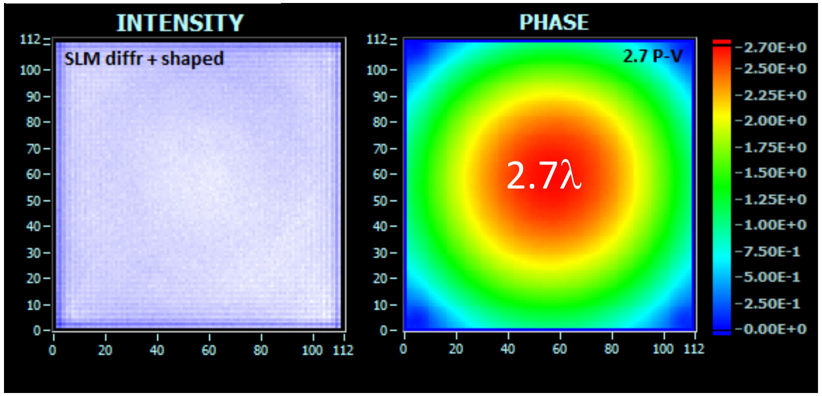
Wavefront distortion measured by Phasics SID4



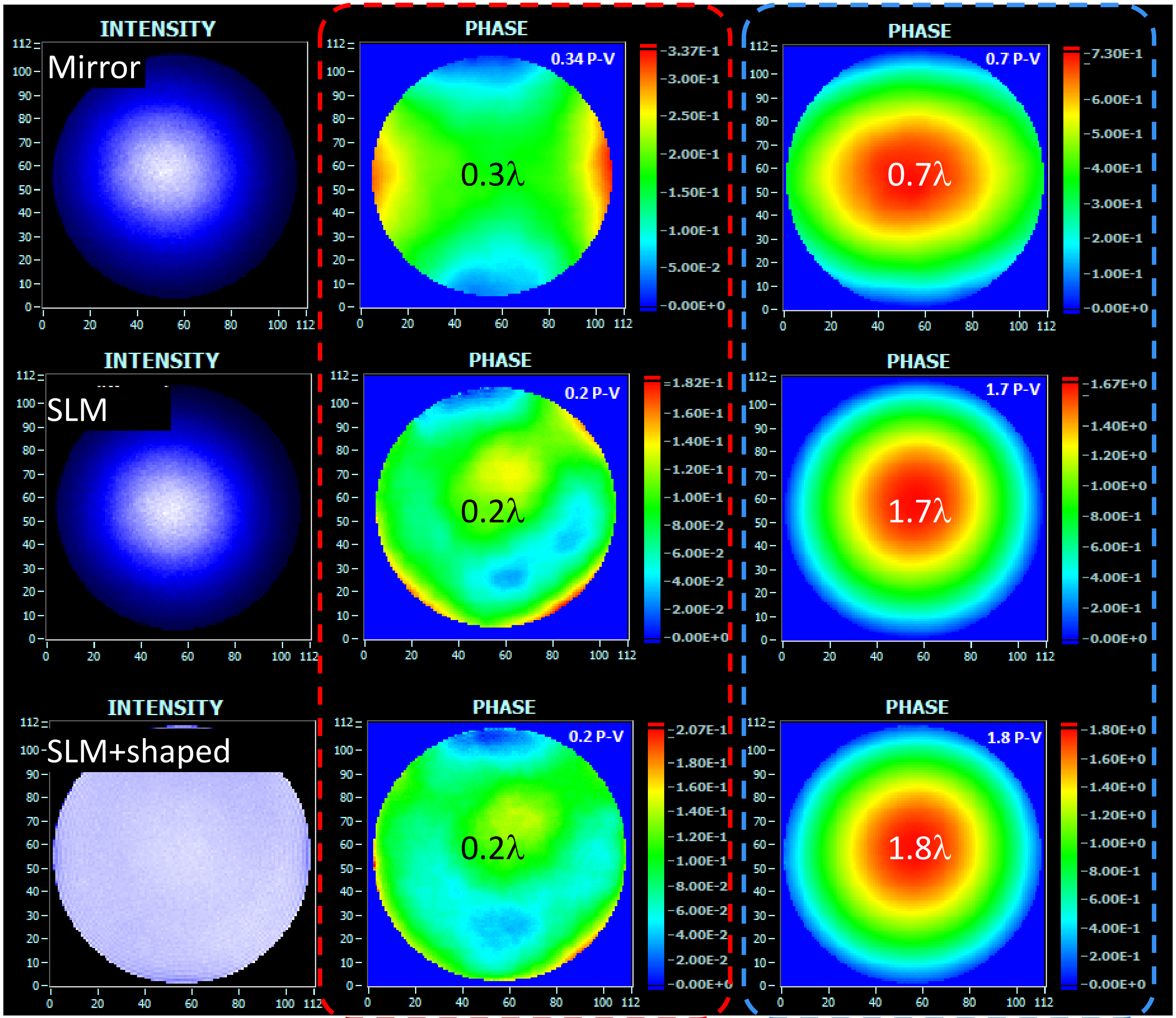


SLM adds constant wavefront aberration of 1.8 λ, but most of it is defocus.

SLM + shaped



Wavefront distortion

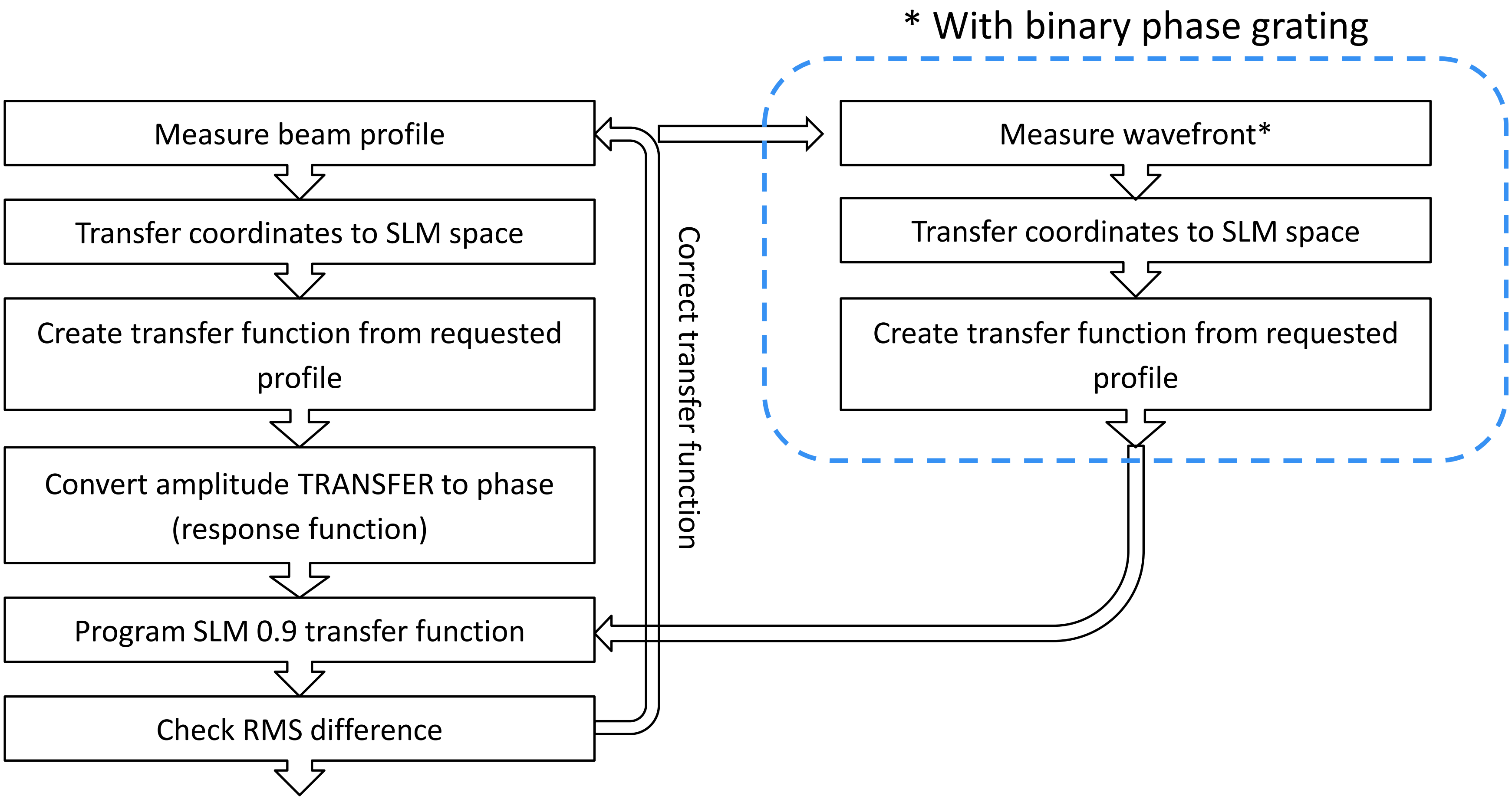


All aberrations

Defocus subtracted

Side-effect: SLM compensates aberrations of the imaging optics

Closed loop operation



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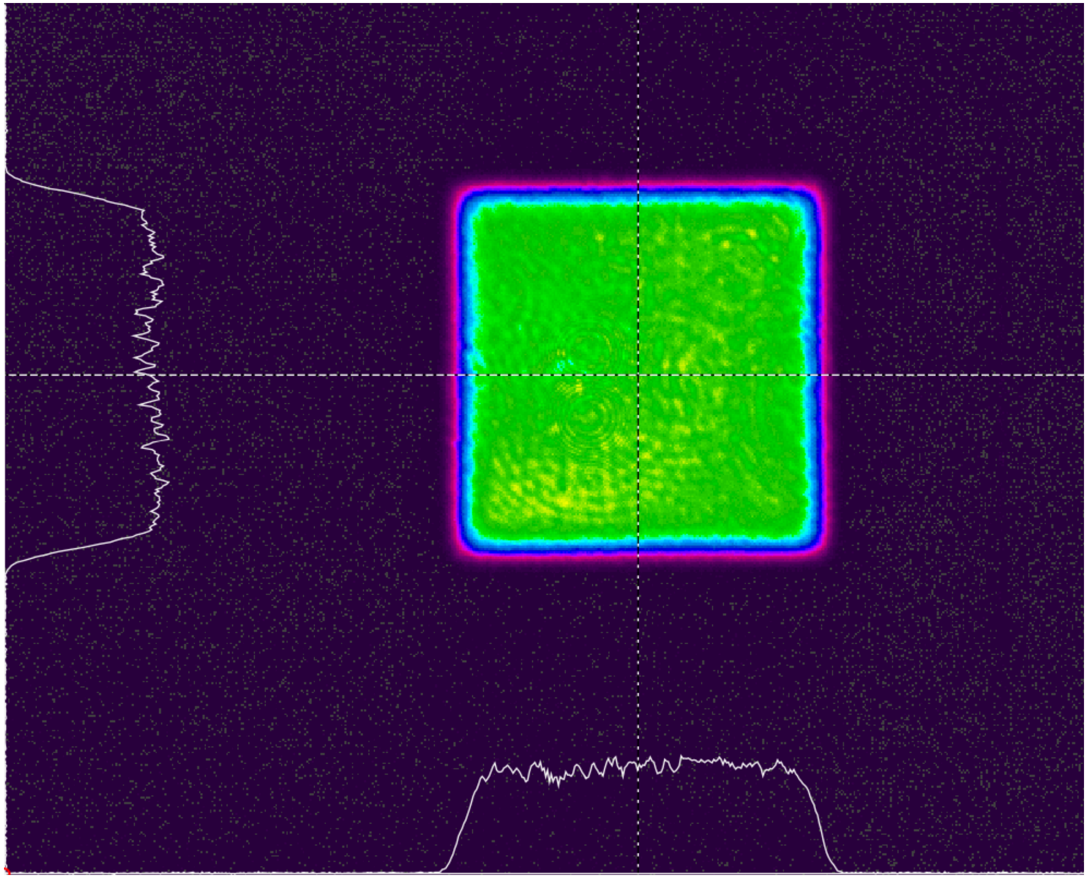
Single iterration shaping

Uses camera output
No feedback yet

Must eliminate diffraction patterns from diagnostic optics.



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Summary

- Liquid crystals can change phase of the propagated light
- Phase change can be used to shape amplitude of the light
- In near-field shaping, wavefront deformation is static
- Beam shaper based on LC will be used in DiPOLE/HiLASE front-end

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